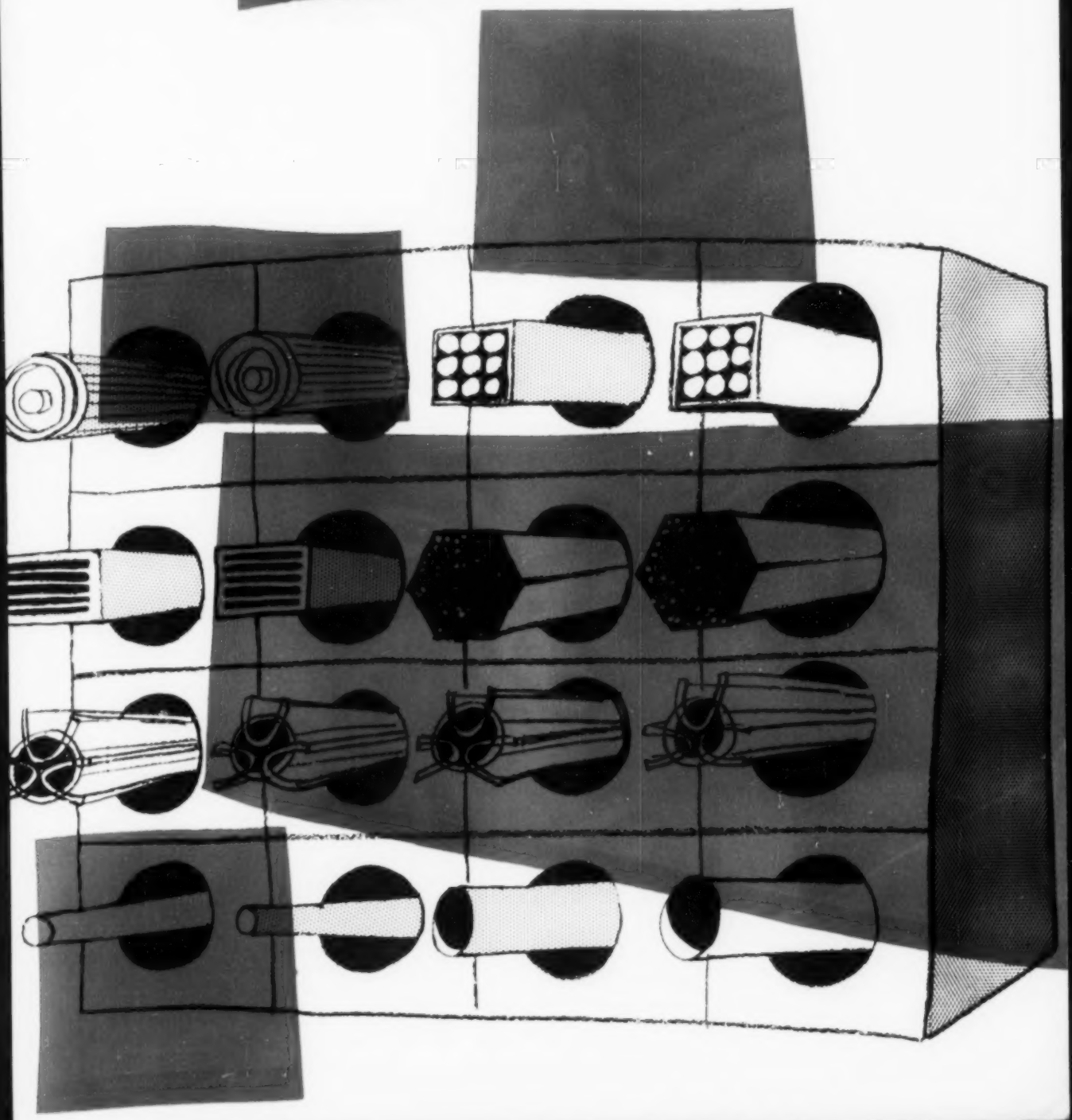
JOURNAL OF

METALS

MAY 1957



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VOL. 9, NO. 5

MAY 1957

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COVER

Cover Artist Irene Trivas depicts nuclear reactor fuel elements, one of the challenges to modern metallurgical research. A review of the 1957 Nuclear Congress is featured in this issue. On the ISD side, the commencement of a three-part history of the blast furnace is found on page 656.

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Published the first day of each month by the American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., 29 West 39th Street, New York 18, N. Y. Telephone: PEnnsylvania 6-9220. Subscription $8 per year for non-AIME members in United States and North, South, and Central America; $10, foreign; $6 for AIME members, or $4 additional in combination with a subscription to "Mining Engineering" or "Journal of Petroleum Technology." Single copies, 75 cents; single copies foreign, $1.00; special issues, $1.50. . . . The AIME is not responsible for any statement made or opinion expressed in its publications. . . . Copyright 1957 by the American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc. . . . Registered cable address, AIME New York. . . . Indexed in Engineering Index, Industrial Arts Index, and Chemical Abstracts. . . . Second class mail privileges authorized at New York, N. Y., and additional entry established at Manchester, N. H. Number of copies of this issue 10,000.

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Sales Engineer, graduate metallurgist, preferably with some experience in the mineral processing industry. Must speak Spanish and be free for quite extensive travel. Salary, open. Company pays placement fee. Headquarters, Midwest. W4724.

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Additional classified advertising appears on pages 632 and 634.

in pressure vessel fabrication and ASME code interpretation, to be responsible for materials and processes applicable to marine nuclear power plants; 2) Development Engineers, B.S. in metallurgical engineering, E.E., or M.E., for development work leading to utilization of new materials and processes. **b)** *Standards Engineers*, B.S.M.E.; familiarity with government specifications; will be responsible for preparation of specifications as applied to making nuclear power plants; editing and preparation of standards and design handbooks and engineering reports. **c)** *Raw Materials Control Engineers*, B.S., metallurgical engineer, M.E. for raw material inspection and advisory responsibility. Salaries, to $8500 a year. Company pays placement fees, interviewing expenses, relocation of dependents, etc. Location, Pennsylvania. W4700.

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Research Engineers, with experience in nonferrous metallurgy, especially the nonferrous extractive metallurgy of lead, zinc, and copper; also a few years experience in pilot plant work or in general smelter test work. **a)** *Metallurgical*, with 5 to 20 years experience, to plan and conduct research on problems of extractive metallurgy. Salary, $8,000 to $12,000 a year. **b)** *Metallurgical*, with one to five years experience, to conduct research on problems of extractive metallurgy. Will assist more experienced engineers. Salary, $6000 to $9000 a year. Location, western Pennsylvania. W4554.

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Engineers, for a research organization. **a)** *Group Leader, Basic Metal Processing Research*, preferably with Ph.D. in mechanical engineering, or a physicist with a doctorate, with strong background in applied mechanics. Several years experience in industrial or academic research in the field of metal processing. Will be responsible for planning and directing basic and long-range research in field of metal processing. **b)** *Metal Cutting Research Engineer or Physicist*, interested in making an original contribution to a basic manufacturing process—machining. Knowledge of elementary machining practice desirable. Will do analytical and experimental work in elastic and plastic material deformation; dynamics; friction; heat conduction; lubrication. Also some work in metallurgy and instrumentation. Research will be done on chip formation in cutting and grinding, effects of friction on plastic flow processes, etc. **c)** *Dynamics and Physical Analysis Research Engineer*, graduate mechanical, with strong mathematical background, for basic machine tool research. Background in mathematical

(Continued on page 632)

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Personnel

(Continued from page 631)

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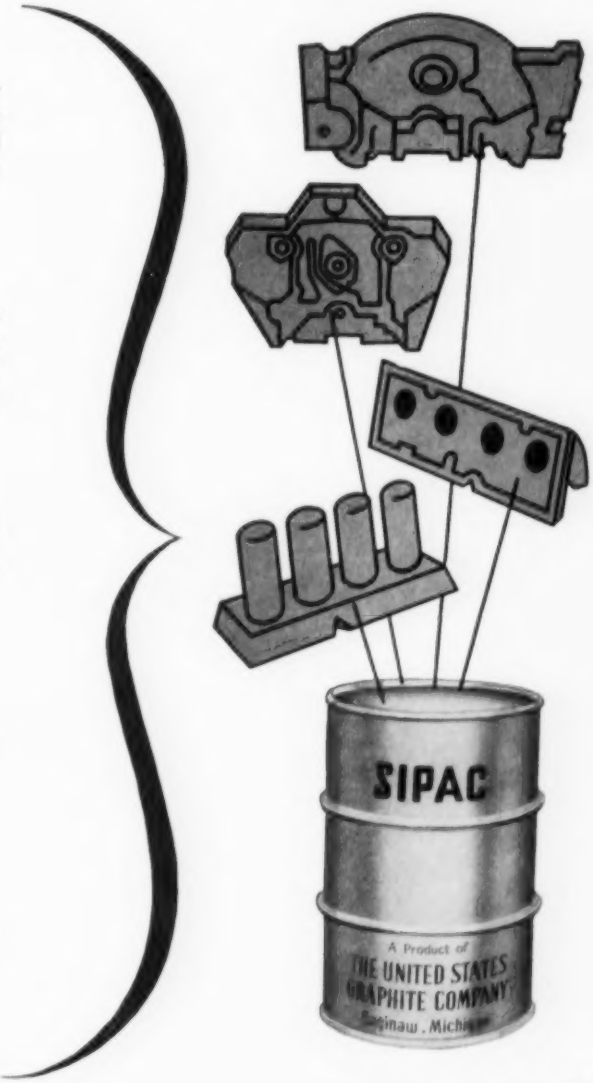

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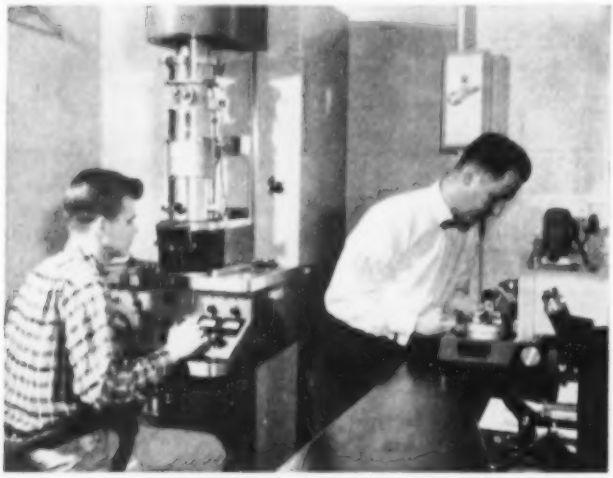

Dr. M. W. Burkart, Fellow Engineer, and Mr. P. Schnizler, technician, are examining the fracture surfaces of UO_2.

Mr. W. A. Bostrom, Senior Engineer, and technician W. Bowen measure gas transport in metals using mass spectrometric analysis.

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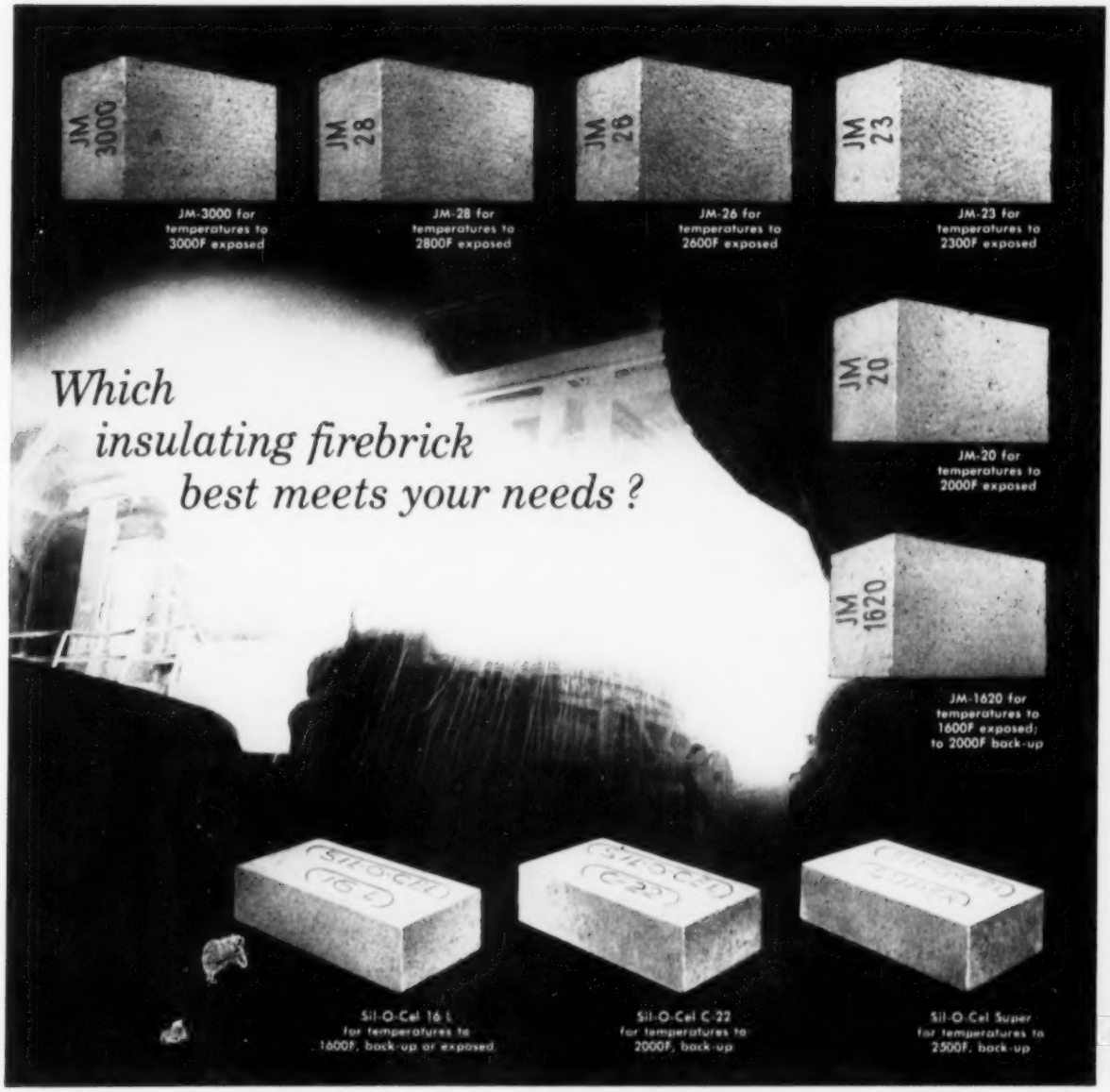
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BOOKS

An Introduction to Electrostatic Precipitation in Theory and Practice, by H. E. Rose and A. J. Wood, Constable, Constable & Constable Co. Ltd., London WC2, England, 166 pp., $2.80, 1956.—This monograph presents a critical review of the subject based on the authors' research. Basic electrical theory, and the efficiency, design, construction, and problems of precipitators are covered. It is intended for the practical man concerned with gas cleaning, as well as for the student. •

Oxygen in Iron and Steel Making, by J. A. Charles, W. J. B. Chater, and J. L. Harrison, *Interscience Publishers Inc.*, 250 Fifth Ave., New York 1, N. Y., 309 pp., $6.50, 1956.—A review of previously published information is included with the results of some unreported trials made by British iron and steelmaking companies. The book is concerned with the treatment of molten metal, including desiliconization of iron, oxygen injection in the open hearth process, the use of oxygen in the bessemer process and the electric arc furnace. Flame and blast enrichment, as applied to the blast furnace, the cupola, and the gas producer, is also discussed in some detail. •

Oxydation von Metallen und Metallegierungen, by K. Hauffe, *Springer-Verlag*, Berlin, Germany, 389 pp., approx. $12.00, 1956.—This treatise on the oxidation of metals and alloys deals with the mechanism of oxidation, the classification of scale, and the outlook on oxidation-resistant materials. It covers general chemical aspects, pitting and diffusion phenomena, scale formation, the action of sulfur and oxygen on specific metals and alloys, and methods of measuring oxidized layers.

Proceedings Connected with the Testimonial Presented to Thomas Messinger Drown, M.D., Secretary of AIME, at Montreal, Sept. 18, 1879. By Members of the Institute. Published by *The Testimonial Committee For Private Distribution*, 19 pp., $3.00.—This cloth-bound edition is obtainable at Stammer's Bookstore, 61 Fourth Ave., New York 3, N. Y.

A brochure and publication's list has recently been issued by the Metal Powder Association covering new standard data sheets, and proceedings of annual meetings from 1946 to 1956, as well as new publications in powder metallurgy. The order form and list is available from Metal Powder Assn., 130 W. 42nd St., New York 36, N. Y.

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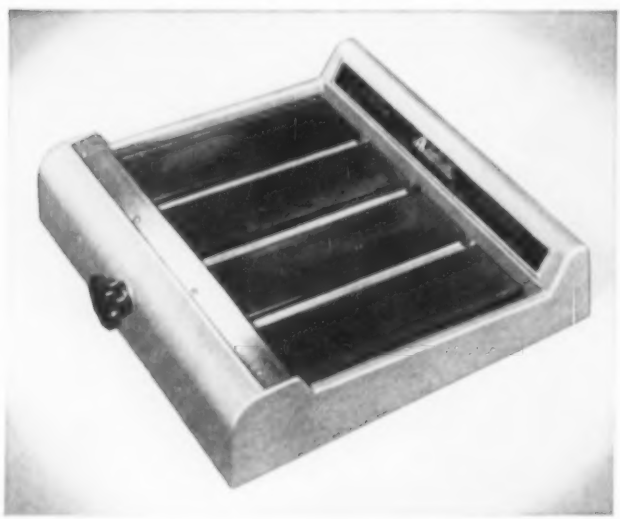
The Trilinear Chart of Nuclides, 2nd ed., compiled by W. H. Sullivan, *U. S. Government Printing Office*, Superintendent of Documents, Washington 25, D. C., 20 pp., $2.00, 1957.—This revised edition of Dr. Sullivan's nuclide chart presents a digest of up-to-date nuclear data in comprehensive form. The information on isotopes is organized into six general classes, including α and β stability and instability, natural occurrence vs man-made production, special designation for fission products, genetic relationships for decay, degree of certainty for the data presented, and presentation of physical data. Explanatory material is included.

A Survey of Available Literature on the Rapid Combustion of Metals in Air, by S. Haffner, *U. S. Dept. of Commerce*, Office of Technical Services, Washington 25, D. C., 18 pp., 50¢, 1956.—This report fulfills the twofold objective of compiling an annotated bibliography of the sources of experimental techniques, and determining what combination of metals is most suitable for photoflash bombs.



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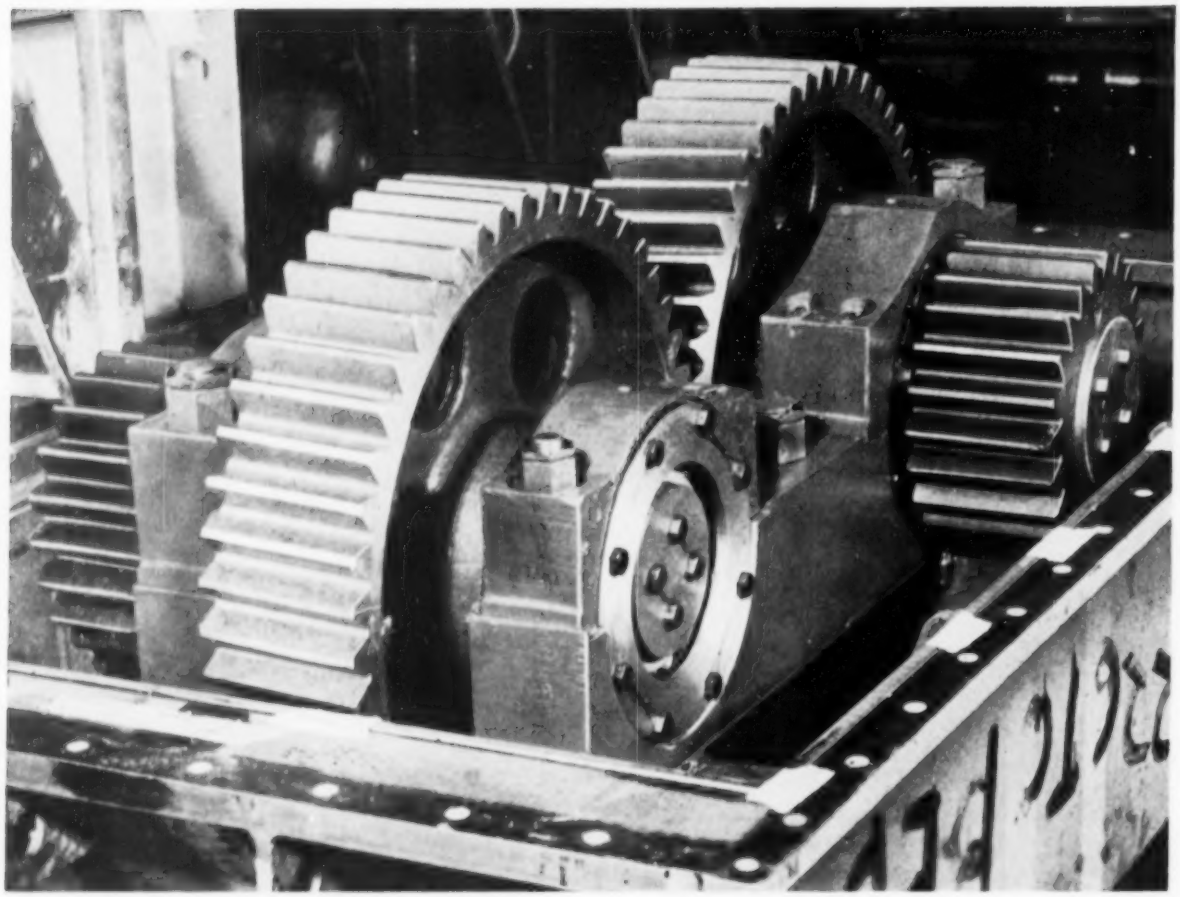

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U. S. Moves Ahead in Nuclear Power Field

There will be five and perhaps six nuclear reactors delivering electric power in the U. S. before the end of 1957. This includes the boiling water reactor which began operation at the Argonne National Laboratory in February; the pressurized water reactor at Shippingport, Pa. with a capacity of 60,000 kw; the sodium reactor and the boiling water prototype power plants in California; and the Army Package Power Plant at Ft. Belvoir, Va. In addition, the homogeneous reactor at Oak Ridge, Tenn. may come into operation this year. By the end of 1962 the AEC expects that there will have been completed at least 18 civilian atomic power plants in the U. S.

Euratom Committee Visits U. S.

Spurred on by the success of the European Coal and Steel Community (ECSC) and Europe's mounting dependence on imported fuels, a trio of European experts visited the U. S. in February to determine the feasibility of major nuclear power installations. Although nuclear power is not completely economic in the U. S., European nuclear power stations can readily enter into competition with oil or coal-powered stations. Since Continental Western Europe produces only small quantities of natural uranium and no enriched uranium, success of Euratom is dependent on a supply of enriched uranium from the U. S. The trio was informed that the U. S. was prepared not only to provide fuels to Euratom, but also to send some of the necessary technicians.

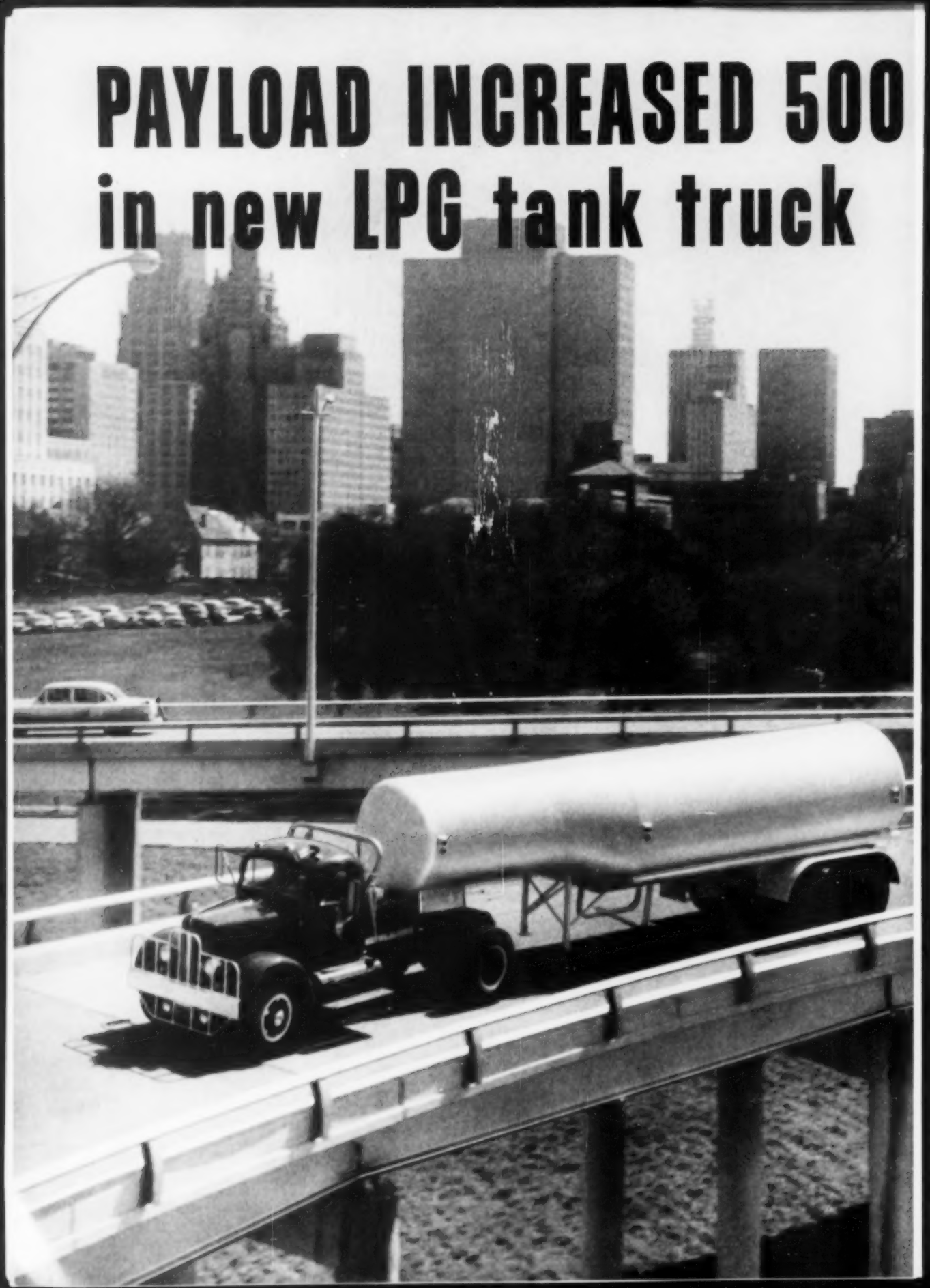
Euratom and European Common Market Founded

ROME, ITALY . . . March 25.—The birth certificate of European federation was signed here today by statesmen of France, West Germany, Italy, Belgium, the Netherlands, and Luxembourg. It was in the form of two treaties which must be ratified by the parliaments of the six countries. One provides for the creation of a European common market and the second, Euratom, creates the European atomic community. This second treaty provides for setting up an atomic energy commission to be directly responsible to a European assembly. It will coordinate and promote atomic research and investment in nuclear power facilities; it has responsibility for supplying the six countries with nuclear fuels of all kinds and will actually own all special fissile materials. Stringent inspection is to be carried out during all stages of processing and use of nuclear materials. Euratom's power goals are for the installation of 3 million kw of nuclear power capacity annually from 1963, reaching 15 million kw by 1967.

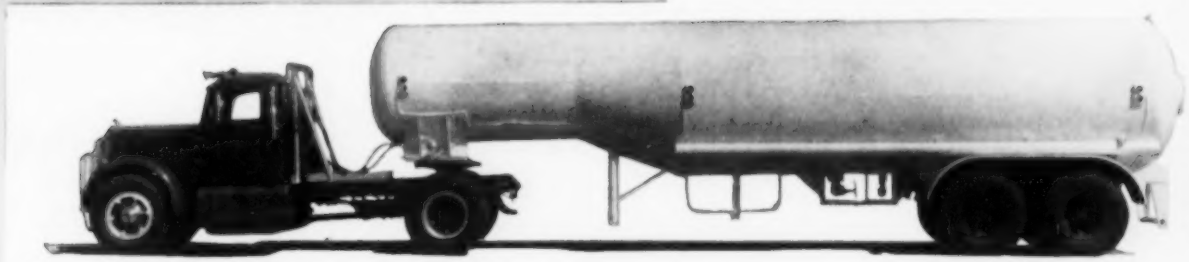
U. K. Announces Augmented Nuclear Power Program

A program to provide Britain with 5 million kw of power from nuclear installations by 1965 has been announced. It calls for construction of 16 atomic power stations in addition to the three now under construction. These three will range in capacity up to 300,000 kw, costing an estimated $386 per kw without initial fuel charges. Consideration is being given to Calder Hall type reactors using slightly enriched fuel to cut capital costs.

PAYLOAD INCREASED 500
in new LPG tank truck



GALLONS



PRESSURE VESSEL ON WHEELS FEATURES

"T-1" STEEL CONSTRUCTION

THE TANKER shown here is an important "first"—it is the *first* LPG trailer tank to be built of "T-1" Constructional Alloy Steel. Because of its vastly superior strength compared to the carbon steel (A-212) usually used for pressure vessels, "T-1" Steel enabled this "pressure vessel on wheels" to carry 500 gallons more payload, though the tank weighs nearly a ton less than its carbon steel twin. It carries 7,750 gallons at a working pressure of 250 psi.

Here is how dead weight was chopped. With A-212 steel, the designer's working stress is normally 21,250 psi. Case 1204 of the ASME Boiler Code permits the designer to go to 26,650 psi with "T-1" Steel—an increase of about 23% in this case. *Shell thickness and weight were reduced one-fifth without any sacrifice of strength or safety.*

USS "T-1" Steel has, in addition to very high yield strength (90,000 psi minimum), exceptional toughness down to very low temperatures. It is weldable—often without preheating or stress relieving. Thus it is ideal for pressure vessels, tanks, standpipes and penstocks.

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Investigate the possibilities of USS "T-1" Steel. Send for our new technical booklet on all phases of its use. Or call a UNITED STATES STEEL SALES OFFICE. United States Steel, Room 2801, 525 William Penn Place, Pittsburgh 30, Pa.

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DEOXIDATION OF STEEL

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Chapter VIII.	Deoxidation of Open Hearth Steel with Manganese-Silicon Alloys by C. H. Herty, Jr., C. F. Christopher, M. W. Lightner and Hyman Freeman. Cooperative Bulletin No. 58. Metallurgical Advisory Board. 71 pages. 1932	477
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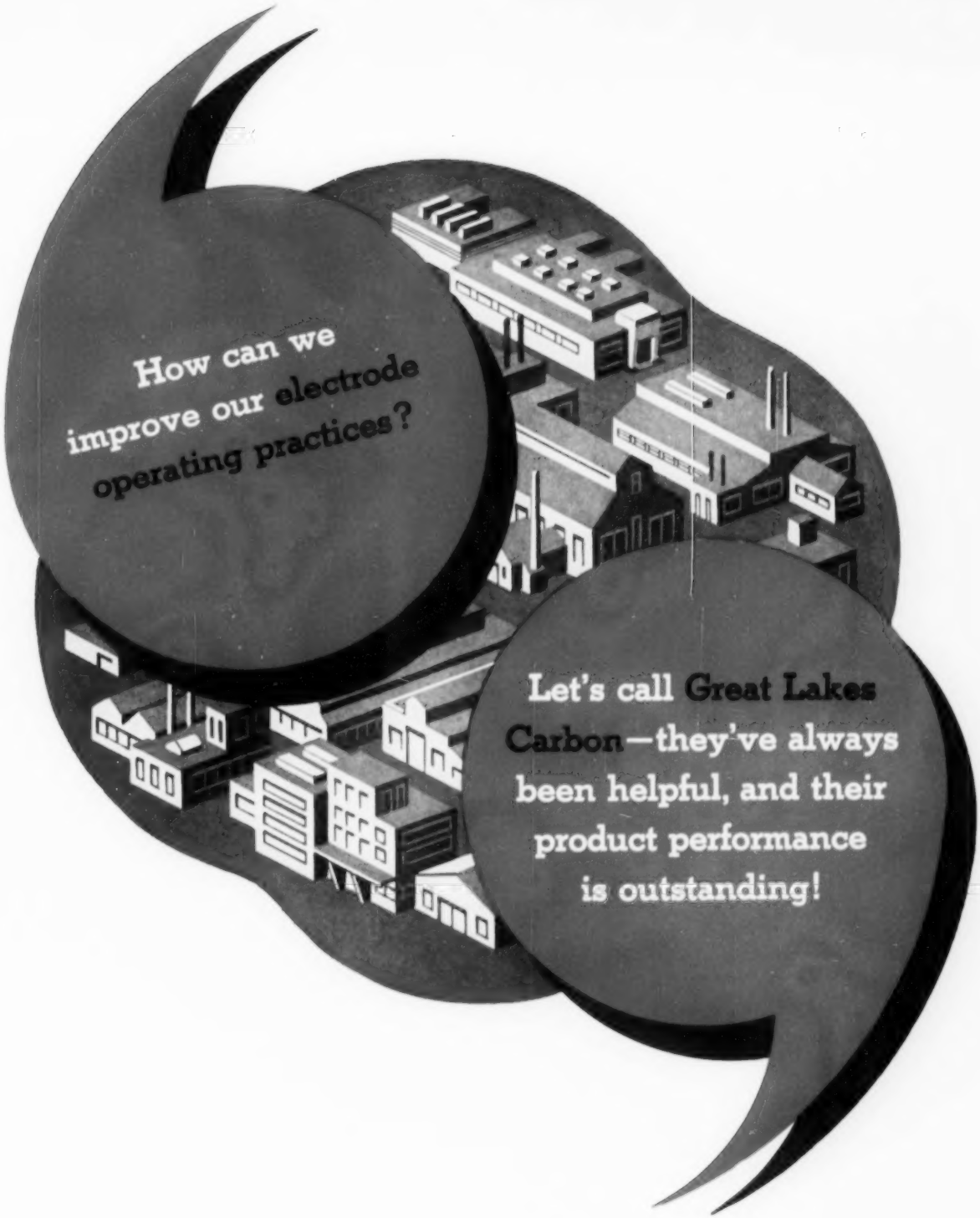
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Sizing and Sintering of Ores

Design and Operation of No. 3 Sinter Strand at Jones and Laughlin's Benson Mines. By R. G. Fleck and F. M. Hamilton.

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Ore Preparation Plant of The Steel Company of Wales Limited—Design, Operation, and Effect on Blast Furnace Performance. By K. C. Sharp and H. R. Tufnail.

Werrton's New Eight-Foot Wide Iron-Ore Sintering Plant. By Julius M. Strassburger.

Blast Furnace Operations

Operating Experiences with High Beneficiated Burdens. By D. Joyce, W. P. Dowhaniuk, and B. Marsden.

The New High-Grade Iron Ores and Agglomerates and Their Effect on Coke Rates. By John Griffen.

Burdening a Blast Furnace for Minimum Costs. By David R. Bailey.

Comparison of Blast Furnace Penetration with Model Studies. By J. B. Wagstaff and W. H. Holman.

Desulphurization of Hot Metal

Application of Theoretical Principles to Desulphurization in Iron and Steel Making. By John F. Elliott.

Desulphurization with Calcium Cyanamid in Hot-Metal Ladles. By G. G. Hatch, G. E. Wagner, and M. Trottier.

Desulphurization of Molten Iron. By J. N. Hornak and E. J. Whittenberger.

Desulphurization of Blast Furnace Iron with Injected Calcium Carbide. By Daniel E. Watkins and J. R. McFarland.

Coal and Coke

Pilot-Scale Coke Ovens—Development and Operation. By R. Tracy Eddinger and John Mitchell.

New Pressure-Recording 18-Inch Test Oven. By R. P. Aikman.

Study of Pressure Relationships in Commercial Coke Ovens. By D. C. Coleman and P. J. Farley.

Low Fuel Rates Obtained with Three-Foot Blast Furnace Using Prepared Ores and Coke-Anthracite Mixtures. By Russell C. Bucht and Miles B. Royer.

Research and Development on Sintering

Reaction Zones in the Iron-Ore Sintering Process (JOURNAL OF METALS Award Paper). By R. D. Burlingame, Gust Eriksmes, and T. L. Joseph.

Sintering Investigations Using Factorial Design Experiments. By T. L. Myron, C. J. Davis, and R. L. Franklin.

Methods for Increasing Production Rate of Flue-Dust Sinter. By E. C. Rudolphy and E. J. Whittenberger.

Sintering Iron Ores and Concentrates at Extaca. By Robert L. Bennett, Robert E. Hagen, and Morris V. Mielke.

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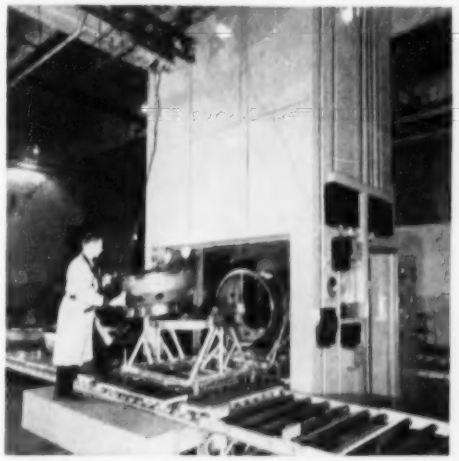

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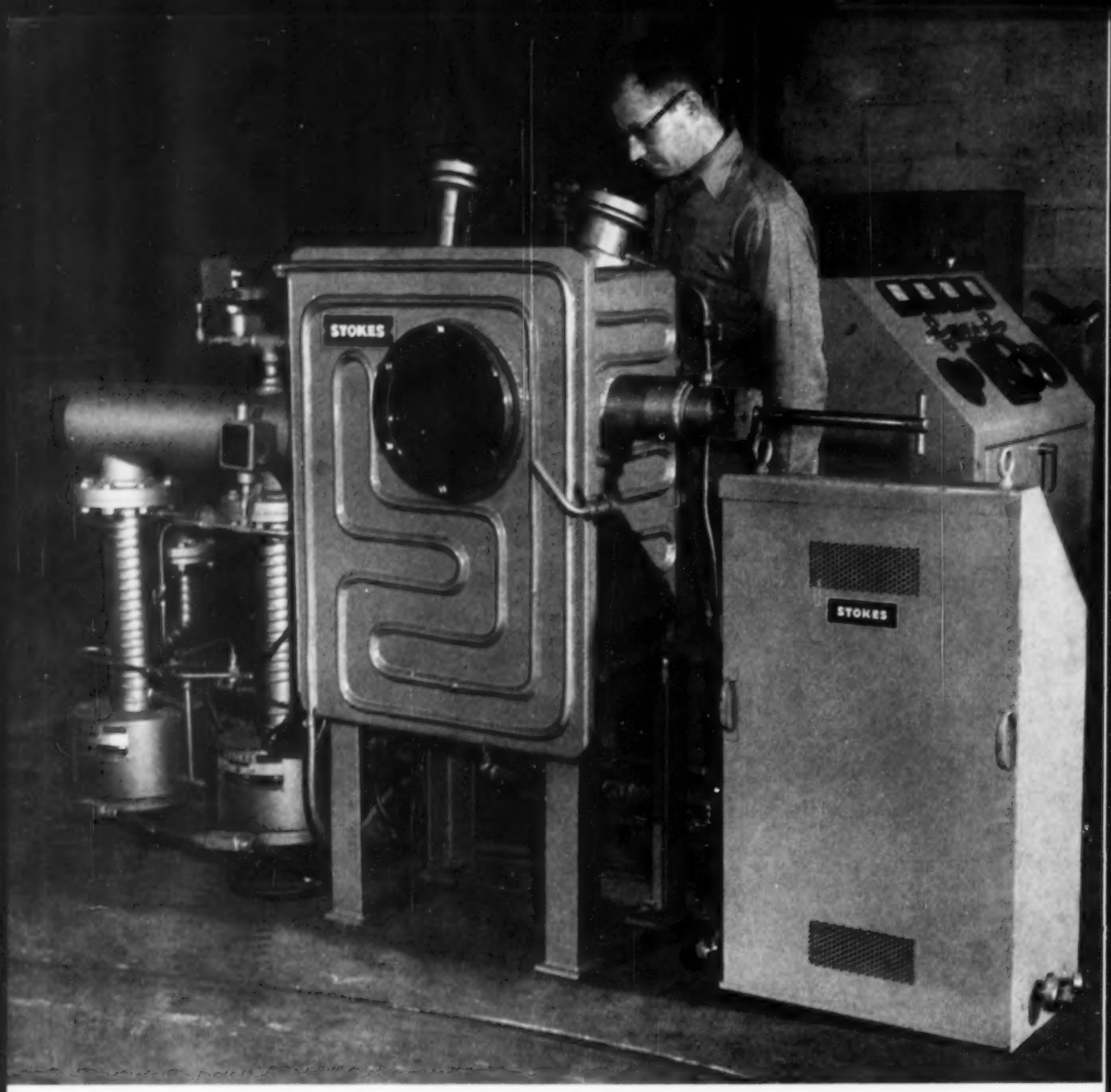
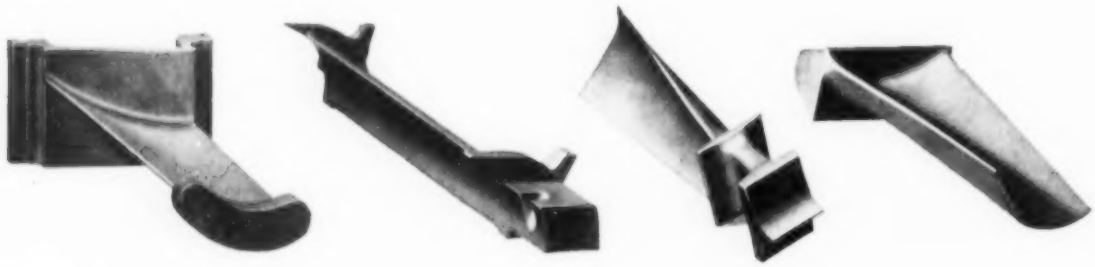


Typical precision castings which Austenal, Inc., Microcast Division, plans to produce with new Stokes Model 437-520 vacuum furnaces.



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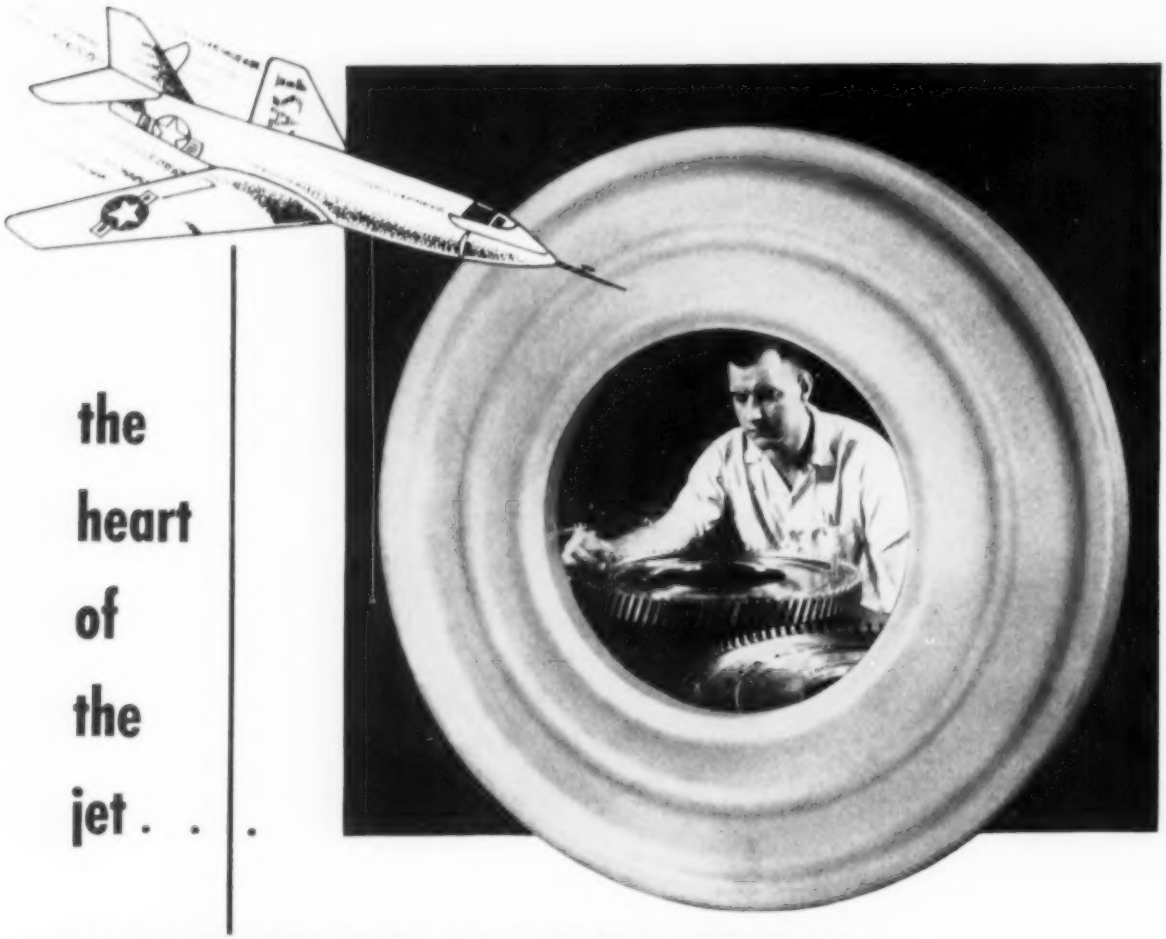

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EDITORIAL

Institute of Metals Division

Announces Programming Changes

IN a search for better means to serve wide range of needs for programs and publications, the Institute of Metals Division Executive Committee has decided as a policy that the programs and publications functions should be separated. During this experiment, publication of a paper will not insure its presentation on a program nor will presentation of a paper on a program insure its publication. Each of these activities will carry out their functions by separate established procedures during this experiment.

Starting May 1, 1957, the IMD will initiate the new procedure for programming papers. After that date, members desiring to present a paper on a program should submit a 200 to 300-word abstract for consideration by the Programs Committee. In general—provided meeting room space is available—all such *abstracts* will be programmed at an IMD meeting and published prior to the meeting. If the author wishes his paper to be published, he should continue the existing procedure of submitting the required number of copies (three) to the Publications Committee. If he wishes to both present and publish his paper, he should submit both the abstract to the IMD Programs Committee and manuscript to the Publications Committee.

The changed procedure will affect programming for the IMD Fall Meeting to be held in Chicago, Nov. 4-6, 1957. However, papers submitted to the Publications Committee prior to May 1, 1957, under the former procedure and approved for publication, will be given the same consideration for scheduling on the IMD Fall Meeting program as if the former procedure continued in effect. In this case, it is not necessary for the author to submit an abstract to the IMD Programs Committee. The brief abstract that introduces his paper will be used in the compilation of published abstracts of papers on the Fall Meeting program, unless the author chooses to submit an enlarged abstract.

Under the new procedure, authors should submit their 200 to 300-word abstracts in three (3) copies to:

IMD Programs Committee
Metallurgical Society of AIME
29 West 39th Street
New York 18, N. Y.

The abstracts should not include photographs, graphs, or diagrams.

Abstracts for consideration for the 1957 IMD Fall Meeting may be submitted up to a deadline date of Aug. 1, 1957.

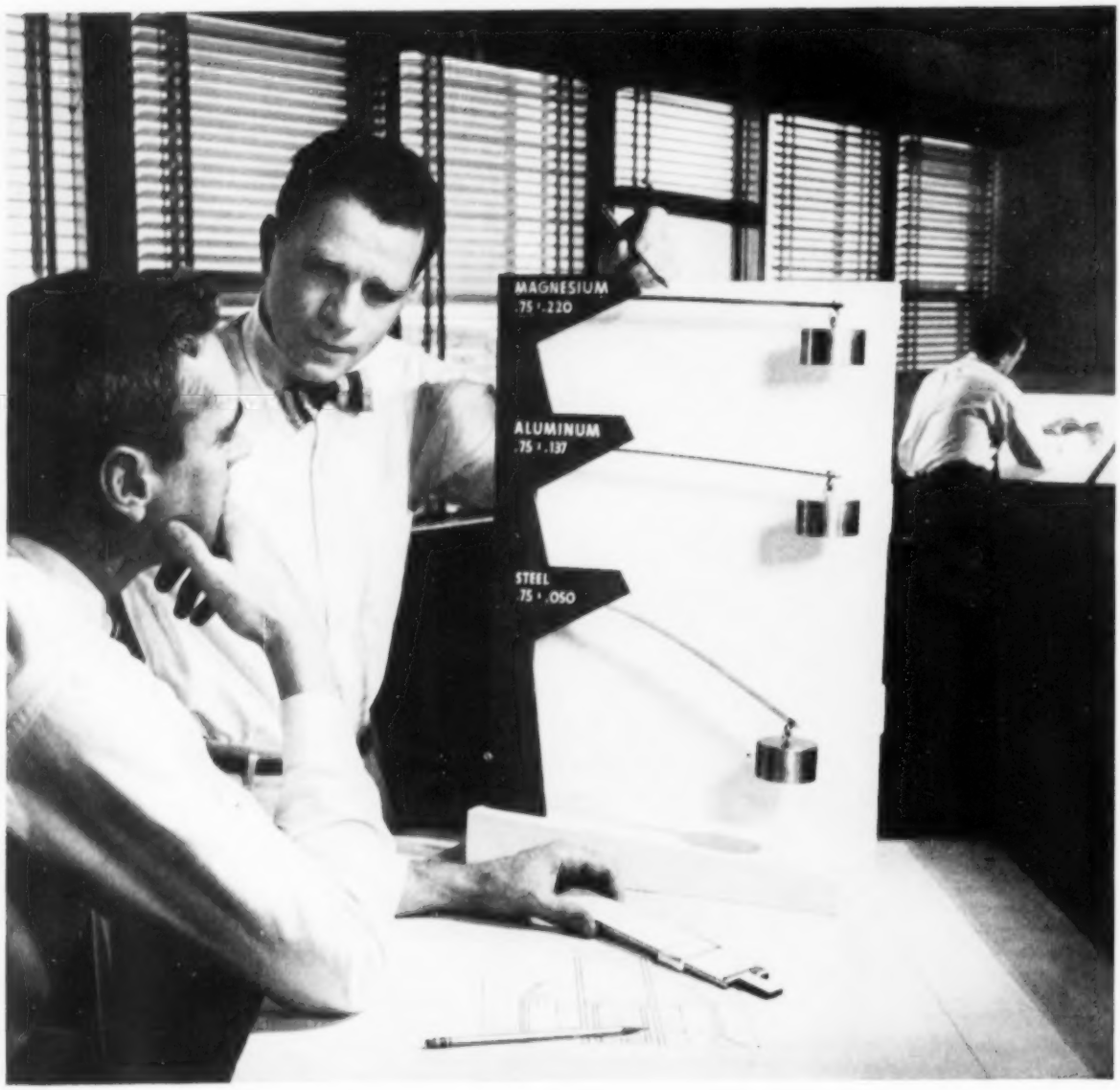
The foregoing remarks apply essentially to the scheduling of oral presentations of research results. Symposiums will be conducted as before by such technical committees as Titanium, Nuclear Metallurgy, Powder Metallurgy, and High-Temperature Alloys.

It is believed that this new procedure offers these advantages.

1) More authors will be able to present research papers, although average presentation time per paper will be briefer.

2) Time between experiment and public announcement will be shorter.

3) Deadline for receiving abstracts can be much closer to meeting time than previously.



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JOHN C. KINNEAR, JR., first President of The Metallurgical Society AIME, is General Manager, Nevada Mines Div., Kennecott Copper Corp., McGill.

A true Nevadan, Mr. Kinnear was born in McGill on Nov. 2, 1914, and attended McGill public schools and White Pine County High School in Ely, Nev. After graduation from Pomona College, Claremont, Calif., with a B.A. degree, he attended Massachusetts Institute of Technology, receiving a B.S. in metallurgy in 1938. During his school years and while attending Pomona College, Mr. Kinnear participated in athletics, an interest he still maintains. His association with AIME began during his years at MIT as a Student Associate.

Initially employed by Nevada Consolidated Copper Corp. during his summer vacations, Mr. Kinnear's main professional association has been with Kennecott Copper Corp., working as dairy laborer, smelter laborer, rodman in the construction department, and power plant helper before graduating from school. His permanent association with the company began in 1938 at the McGill Smelter. Transferring to the Chino Mines Div., Hurley, N. M., in 1939, Mr. Kinnear, as smelter engineer, had the opportunity to be present at the initiation of the Hurley smelter—the *blowing in* or start of operations—on May 2, 1939. He became assistant superintendent of the smelter in 1942. Promoted to assistant to the general manager, Mr. Kinnear returned to McGill, Nev., in 1948, and became assistant general manager, Nevada Mines Div., in 1949. He assumed his present duties as general manager in 1950.

Interested in AIME since his student days at MIT, Mr. Kinnear has been active both on the Local Section and National levels. He has served as chairman of the Nevada Section and as chairman of the papers and program committee of the Extractive Metallurgy Div. Before his election as the first president of the newly organized Metallurgical Society of AIME, Mr. Kinnear was chairman of EMD. His professional and civic interests are of broad scope: in addition to AIME he is a member of the Mining and Metallurgical Society of America; has acted on the board of governors, Western Div., American Mining Congress; and is a member of the executive committee of the Nevada Mine Operators' Assn.

Mr. Kinnear married the former Helen Poor of Peabody, Mass., in 1939, and they have three children: Marcia, Sheila, and John Charles Kinnear, III.

Arthur W. Thornton

Past-President

Arthur W. Thornton, assistant to the vice president-operations, National Tube Div., U. S. Steel Corp., Pittsburgh, is past-president of the Metallurgical Society of AIME. As chairman of the Metals Branch Council during the year 1956-1957, he took a leading part in the organization of the new Society. His efforts in developing and correcting the Metallurgical Society Bylaws were largely responsible for their present status; he detected some of their structural flaws and aided in the solution of drafting problems. A former chairman of ISD, Mr. Thornton has served on the executive committee of the NOHC and on the AIME Bessemer Committee (now the AIME Converter Steel Committee). A native of McKeesport, Pa., Mr. Thornton graduated from Lehigh University in 1931 with a degree in metallurgical engineering. He was associated with the Weirton Steel Co., W. Va., before joining the metallurgical department of the Duquesne Works, U. S. Steel Corp. Since 1934, he has been with the National Tube Div. as successively, steel works metallurgist, superintendent of the open hearth, bessemer, and blast furnace departments, and assistant general superintendent. He attained his present post in 1954. Mr. Thornton engages in much traveling in connection with his work, but he still finds time to relax in the warm waters of Florida and to pursue his favorite hobby, color and stereoptic photography.

James B. Austin

Director

James B. Austin, vice president-fundamental research, U. S. Steel Corp., Pittsburgh, has been elected a director of the Metallurgical Society. A native of Washington, D. C., he received a chemical engineering degree from Lehigh University in 1925 and a Ph.D. in physical chemistry from Yale University in 1928. He joined U. S. Steel at Kearny, N. J., in 1928, gaining his early experience in the steel industry on the staff of the newly-organized Research Laboratory. His continued association with U. S. Steel led to a promotion, in 1944, to the position of assistant director of the laboratory, from which he rose to become director two years later. He was named to his present position in 1956. A member of AIME since 1944, he has made important contributions in the area of publications, and has served on the executive committee of IMD. Besides the active role which he plays in the AIME, Mr. Austin extends his participation in professional activities to include membership in ASM, of which he was president in 1953.

Donald L. Clark

Director

Donald L. Clark, melting superintendent at Simonds Saw and Steel Co., Lockport, N. Y., has been elected to the Board of Directors of the Metallurgical Society. A graduate of Michigan College of Mining and Technology in Houghton, he earned a master's degree and one as a metallurgical engineer there in 1933. Upon completion of his graduate studies, he joined Crucible Steel Co. of America. Leaving his position in 1938, he became a member of the staff of Simonds. Since 1941, he has been actively associated with AIME, serving on the first board of directors of the Niagara Frontier Section, organized in 1954, and as chairman of the Electric Furnace Steel Conference Committee in 1956. His most recent affiliation in AIME has been with ISD's Electric Furnace Steel Conference, serving as Chairman of the Executive Committee. He is also affiliated with the Electric Metal Makers Guild, acting as president of this organization for the 1950-51 term, and is a member of the American Society for Metals.

Harold Emerick

Director

Harold B. Emerick, a director of the Metallurgical Society, studied metallurgy at Carnegie Institute of Technology, Pittsburgh. He joined Jones & Laughlin Steel Corp. in 1935 at its Aliquippa, Pa., Works Div. After working as a metallurgical investigator and supervisor of the steel works metallurgical division, he was appointed assistant chief metallurgist, Aliquippa Works. His next assignment in 1951 brought him to the headquarters (Pittsburgh) technical staff as assistant to the vice president-technology. In 1953, he became an assistant director in the technical services division, advancing to director in 1955. An active participant in AIME affairs, Mr. Emerick is currently serving as chairman of ISD. His literary virtuosity has been an interesting sidelight to Mr. Emerick's career. Author or co-author of some 15 published articles, he was a recipient of the Frank B. McKune Memorial Award of AIME in 1942 and co-edited a book on open hearth steelmaking, *Basic Open Hearth Steelmaking*, published by AIME.

Walter R. Hibbard, Jr.

Vice President

Walter R. Hibbard, Manager of Alloy Studies at the General Electric Research Laboratory, Schenectady, is serving as vice president of the Metallurgical Society for 1957. In addition to this new post he will act as chairman of IMD for 1957. Dr. Hibbard, a native of Bridgeport, Conn., graduated from Wesleyan University in 1939 with a degree in physical chemistry, and received a doctorate in physical metallurgy from Yale University in 1942. After three years with the metallurgical section of the Bureau of Ships, USN, he returned to Yale as an assistant professor, later becoming an associate professor. He is presently an adjunct professor of metallurgical engineering at Rensselaer Polytechnic Institute. Dr. Hibbard joined the staff of General Electric's Research Laboratory in 1951, and was appointed assistant manager of the Materials and Processes Section the following year. In 1953 he assumed his present post. He has been active in IMD since 1942, serving successively on the Programs Committee, the Mathewson Gold Metal Committee, the Publications Committee, and the Executive Committee. An author of more than 60 papers in the field of physical metallurgy, he has constantly endeavored to assure high standards in AIME technical publications. A 1950 recipient of the AIME Rossiter W. Raymond award, he is an active member of the Boy Scouts of America organization in Schenectady.

John D. Sullivan

Director

John D. Sullivan, a director of the Metallurgical Society, is a technical director, Battelle Memorial Institute, Columbus, Ohio. Educated at the universities of Montana and Washington, he was with the U. S. Bureau of Mines prior to joining Battelle in 1931. A former chairman of the Douglas Award Committee, Mr. Sullivan has been an active member of AIME since 1930. He was one of the founders of the Extractive Metallurgy Division, acting as its first chairman from 1948 to 1950. He has been a member of the Executive Committee and Publications Committee of EMD since its inception. He also has served on the Executive Committees of both IMD and IndMD. Besides the important role he plays in AIME, Mr. Sullivan includes the American Ceramic Society, ASTM, The Electrochemical Society, the Faraday Society, The Chemical Society of London, the Geochemical Society of America, and the British Ceramic Society among his professional affiliations. He has published over 100 articles in the areas of metallurgy, chemistry, and ceramics.

T. D. Jones

Director

T. D. Jones, a native of Wales, Wisc., graduated from the University of Wisconsin, Madison, with a bachelor's degree in metallurgy in 1922. He received his professional degree of metallurgical engineer in 1929, also from the University of Wisconsin. Since graduation from college, he has served with one company, American Smelting and Refining Co., beginning his association with the organization in August 1922, at the Omaha, Neb., plant. His career with the company has been continuous, and at present, Mr. Jones fills the position of chief lead refinery metallurgist. A member of AIME since 1931, he has for many years played a major role in the Extractive Metallurgy Division, and was chairman in 1952. He has also served on the EMD Executive Committee, the all-Institute Admissions Committee, and the National Steering Committee. The new director was one of six prominent graduates of the College of Engineering at the University of Wisconsin awarded a citation last year for distinguished engineering services on Engineers' Day, May 4.

Herbert H. Kellogg

Director

Herbert H. Kellogg, Professor of Mineral Engineering, Columbia University School of Mines, is a native New Yorker. After receiving his B.S. and M.S. degrees from Columbia, he joined Pennsylvania State College as instructor of mineral preparation, later becoming assistant professor. In 1946 he returned to Columbia to teach extractive metallurgy. Professor Kellogg has been a member of AIME since 1940, and active in the affairs of the EMD since its formation in 1950. He fathered the Committee on Physical Chemistry of Extractive Metallurgy and was its chairman from 1950-1952. A former chairman of the Papers and Programs Committee and the Electrolytic Extractive Processes Committee, he has been serving as chairman of the EMD Technical Publications Committee, and will act as chairman of EMD for next year. Author of numerous technical articles, he has been intimately concerned with the titanium industry since his appointment as chairman of the Titanium Advisory Committee, Office of Defense Mobilization, in 1954.

C. S. Smith

Director

Cyril Stanley Smith, a native of England, received his B.Sc. from the University of Birmingham in 1924 and his Sc.D. from Massachusetts Institute of Technology. After a brief period as research associate for MIT, he joined the American Brass Co., leaving his post to continue studies in the properties of alloys abroad. During World War II, Dr. Smith served as research supervisor on the National Defense Research Committee and the War Metallurgy Committee, National Research Council, and was in charge of the metallurgical work on fissionable materials for the atomic bomb at Los Alamos Scientific Laboratory, Manhattan District. In 1946, he went to the University of Chicago as professor of metallurgy; under his guidance the Institute for the Study of Metals was established, of which he is the first director. Mr. Smith is a member of many government advisory panels, including the AEC and Materials Advisory Board. He is the recipient of the Hunt Award and the Mathewson Gold Medal of AIME.

C. T. Marshall

Director

C. T. Marshall, newly elected director of the Metallurgical Society, has been chairman of the AIME Blast Furnace, Coke Oven, and Raw Materials Committee, formerly serving as chairman of its Finance and Membership Committees. Born in Dunbar, Pa., he attended the University of Virginia, receiving a B.S. degree in 1950. After two years service with the U. S. Army Air Corps during World War II, he was a steel mill apprentice during summer vacations, and began his career with Pittsburgh Coke & Chemical Co. in 1950. Starting as practice engineer and raw materials supervisor, he was promoted to assistant plant manager not long afterward, becoming assistant to the executive vice president in 1954. The following year he attained his present position of general manager of the Coke and Iron Div., assuming additional duties meanwhile as vice president-operations for the subsidiary, Neville Ferro Alloy Co. Also director of Kerchner, Marshall & Co., he lists among his professional affiliations AISI, and the Assn. of Iron & Steel Engineers.

E. E. Schumacher

Director

Earle E. Schumacher is qualified for the office of director by many years of service both to AIME of which he is a past director, and to the Institute of Metals Division, to which he contributed much as chairman. Author of many technical papers, he delivered the Annual Lecture of IMD in 1950, and in the same year the Autumn Lecture of the British Institute of Metals. Born in Chelsea, Mich., Dr. Schumacher received his technical training at the University of Michigan. In 1918 he joined the research laboratories of the Western Electric Co., which were later incorporated into the Bell Telephone Laboratories. He has been with the Bell System for the past 39 years, and was instrumental in the organization of the metallurgical research department, of which he is director. His major contribution lies in his early recognition of the vital role metallurgy would and does play in the ever expanding technology of communications, a view which in 1956 earned him the honorary degree of D.Eng. from the South Dakota School of Mines and Metallurgy.

Standing Committees of the Metallurgical Society

Standing Committees shall be appointed by the President, subject to confirmation by the Board of Directors at each annual meeting of the Board. (Article VII, Section 1.)

The Bylaws provide for eight Standing Committees of the new Metallurgical Society. Given below and on the following pages is information on each Committee and its members with a pertinent quotation from the Bylaws.

Publications Committee

J. S. SMART, JR.
Chairman

The Publications Committee shall determine publication policies of the Society, shall have authority to accept or reject papers to be published in the publication(s) of the Society, and shall have the duty of preparing and maintaining a publications budget. (Article VII, Section 6.)

Members of the Publications Committee are: J. S. Smart, Jr., American Smelting & Refining Co., *Chairman*; J. B. Austin, U. S. Steel Corp.; John Chipman, Massachusetts Institute of Technology; Gerhard Derge, Carnegie Institute of Technology; S. J. Dickinson, American Smelting & Refining Co.; G. R. Fitterer, University of Pittsburgh; W. J. Harris, Jr., Battelle Memorial Institute; J. H. Hollomon, General Electric Co.; H. H. Kellogg, Columbia University; P. T. Stroup, Aluminum Co. of America.

The Publications Committee will retain final review authority formerly held by the AIME Technical Publications Committee. The Committee will also consider the publications policies of the Society so that the journals published will best meet the needs of the membership, and at the same time be financially feasible.

Education Committee

R. SCHUHMANN, JR.
Chairman

The Education Committee shall devise a program to promote high standards in the education of metallurgists and metallurgical engineers. (Article VII, Section 8.)

Members of the Education Committee are: R. Schuhmann, Jr., Purdue University, *Chairman*; E. S. Machlin, Columbia University; W. O. Philbrook, Carnegie Institute of Technology; D. V. Ragone, University of Michigan; T. A. Read, University of Illinois; A. W. Schlechten, Missouri School of Mines; C. R. Taylor, Armco Steel Co.

The Education Committee has the immediate task of formulating a program that can be integrated with the objectives of the AIME Council on Education, and also with the education committees of EMD and IMD. The Education Committee intends to develop standards for education in the field of metallurgy.

Nominating Committee

A. W. THORNTON
Chairman

The Nominating Committee shall select: a. The nominee for Vice President (President-Elect) of the Society. . . . ; b. Every third year, the nominee for President-Elect of AIME. . . . ; c. One nominee to serve as Director of AIME for a three-year term; d. Nominees for Directors of AIME to fill unexpired terms on the Board of Directors. . . . (Article VIII, Section 1.)

Members of the Nominating Committee are: A. W. Thornton, U. S. Steel Corp., *Chairman*; C. S. Barrett, University of Chicago; John Chipman, Massachusetts Institute of Technology; Morris Cohen, Massachusetts Institute of Technology; T. D. Jones, American Smelting & Refining Co.; C. C. Long, St. Joseph Lead Co.; R. R. McNaughton, Consolidated Mining & Smelting Co. of Canada Ltd.; J. H. Scaff, Bell Telephone Co.; T. S. Washburn, Inland Steel Co.

The Nominating Committee has the responsibility of selecting men of caliber for officers of the Metallurgical Society and for positions on the AIME Board of Directors.

Membership Committee

C. M. SQUARCY
Chairman

The Membership Committee shall be responsible for coordination of membership activities. (Article VII, Section 7.)

Members of the Membership Committee are: C. M. Squarcy, Inland Steel Co., *Chairman*; R. C. Cole, Vitro Uranium Corp.; J. H. Keeler, General Electric Co.; M. E. Nickel, International Harvester Co.

The Membership Committee will have the responsibility of coordinating the activities of the membership committees of the three Divisions, and to work out programs jointly with the other Societies through the national Membership Committee.

Committee on the Metallurgical Profession

MORRIS COHEN
Chairman

The Committee on the Metallurgical Profession shall promote high standards in the profession of metallurgy and metallurgical engineering, and shall have the authority to cooperate with organizations having similar objectives. (Article VII, Section 10.)

Chairman of the Committee on the Metallurgical Profession is Morris Cohen, Massachusetts Institute of Technology. Balance of this Committee has not yet been appointed.

This Committee has a distinct advantage in that it is an overall Society function and has not inherited its prerogatives from Division committees. It is the intention of this Committee to dissolve barriers and to work with other committees *across the board.*

Admissions Committee

H. K. WORK
Chairman

The Admissions Committee shall be responsible for reviewing the qualifications of candidates for membership and presenting the names of recommended candidates through the Society, AIME, to the Board of Directors of AIME for approval. (Article VII, Section 11.)

Members of the Admissions Committee are: H. K. Work, New York University, *Chairman*; Francis B. Foley, International Nickel Co.; T. D. Jones, American Smelting & Refining Co.; E. S. Machlin, Columbia University; J. H. Scaff, Bell Telephone Co.; Paul Von Stein, U. S. Metals Refining Co.; T. B. Winkler, Bethlehem Steel Co.

The Admissions Committee will examine the credentials of individuals applying for membership in the Metallurgical Society of AIME.

Programs Committee

W. J. HARRIS, JR.
Chairman

The Programs Committee shall coordinate program plans and provide for such joint programs among the divisions as are deemed advisable. (Article VII, Section 5.)

Members of the Programs Committee are W. J. Harris, Jr., Battelle Memorial Institute, *Chairman*; J. F. Elliott, Inland Steel Co.; A. E. Lee, Jr., American Metal Co. Ltd.; Ray L. Smith, Franklin Institute.

The Programs Committee will endeavor to forward these immediate objectives: 1) develop an overall program policy for the Metallurgical Society, 2) establish all technical fields that the Metallurgical Society should cover, and 3) organize one joint program for presentation at the next AIME Annual Meeting to cover all Divisions of the Society.

Finance Committee

T. K. GRAHAM
Chairman

The Finance Committee shall prepare the annual budget, and examine, plan for, and submit recommendations concerning the financial condition and welfare of the Society for consideration of the Board of Directors. (Article VII, Section 4.)

Members of the Finance Committee are: T. K. Graham, International Smelting & Refining Co., *Chairman*; W. R. Hibbard, Jr., General Electric Co.; Max Lightner, U. S. Steel Corp.

The Finance Committee will every year review the financial needs of the Society and will recommend a budget. An additional first task will be a study of the means of providing a working fund to finance special projects that the new Society may wish to initiate.

Bylaws of the Metallurgical Society of AIME

Article I

Name and Object

Section 1. This unit of the American Institute of Mining, Metallurgical, and Petroleum Engineers Inc. shall be known as The Metallurgical Society of AIME.

Section 2. The object of the Society is to promote the advancement of metallurgical knowledge and the advancement of the metallurgical profession as a whole by:

a. Providing a medium for communication and cooperation among those interested in any phase of theoretical and applied metallurgy, including those advancing, practicing, learning, or otherwise primarily concerned with the science, engineering, economy, or technology of the metals industry (both producers and consumers). The major metallurgical fields encompass particularly the understanding and knowledge of metal behavior, the manufacturing practice for extracting, refining, and fabricating metals, and the development and application of metals and their alloys.

b. Providing an organization to represent the metallurgists and metallurgical engineers on matters pertaining to education, and to encourage and advance education in the broad field of metallurgical science and engineering.

c. Dissemination of metallurgical knowledge by the holding of professional meetings, and by the preparation, presentation, discussion, and publication of technical papers.

d. Promoting high standards in the profession of metallurgical engineering.

Article II

Members

Section 1. Any member of AIME in good standing may become a member of the Society by indicating his choice in writing to AIME headquarters. Members of the Society will receive the monthly journal(s) of the Society as part consideration for annual dues received. Only members in good standing in the AIME shall have privileges in the Society, and shall hold office in the Society and its Divisions.

Article III

Funds

Section 1. The expenditure of funds received by the Society shall be in conformity with rules established by the Board of Directors of the Society.

Section 2. Dues or assessments in addition to the regular dues of AIME may be fixed by the Board of Directors of the Society, subject to the approval of the Board of Directors of AIME.

Section 3. The Board of Directors shall authorize the disbursement of funds for special purposes such as Awards, Scholarships, and Endowments.

Section 4. The officers of the Society shall submit an annual budget for approval of the Board of Directors of AIME, and shall operate the affairs of the Society in such manner as to assure a balanced budget as determined by AIME bookkeeping practices.

Article IV

Meetings

Section 1. The Society shall meet at the same time and place as the Annual Meeting of AIME and at such other times as may be determined by the Board of Directors.

Section 2. The annual business meeting shall be held within a few days before or after the annual business meeting of the AIME.

Section 3. At a meeting of the Society, for which notice has been sent to the members of the Society through the regular mail or by publication in the Society's journal(s) at least one month in advance, a business meeting may be convened by order of the Board of Directors and any routine business may be transacted which is not inconsistent with these Bylaws or with the Constitution or Bylaws of the AIME.

Section 4. Twenty-five members of the Society shall constitute a quorum for the transaction of business at a regular constituted meeting.

Article V

Officers

Section 1. The officers of the Society shall consist of President, Vice President, Past-President, and Secretary-Treasurer.

Section 2. The Vice President shall be the President-Elect, and shall automatically succeed to the office of President at the end of his term as Vice President.

Section 3. The Board of Directors shall consist of the following:

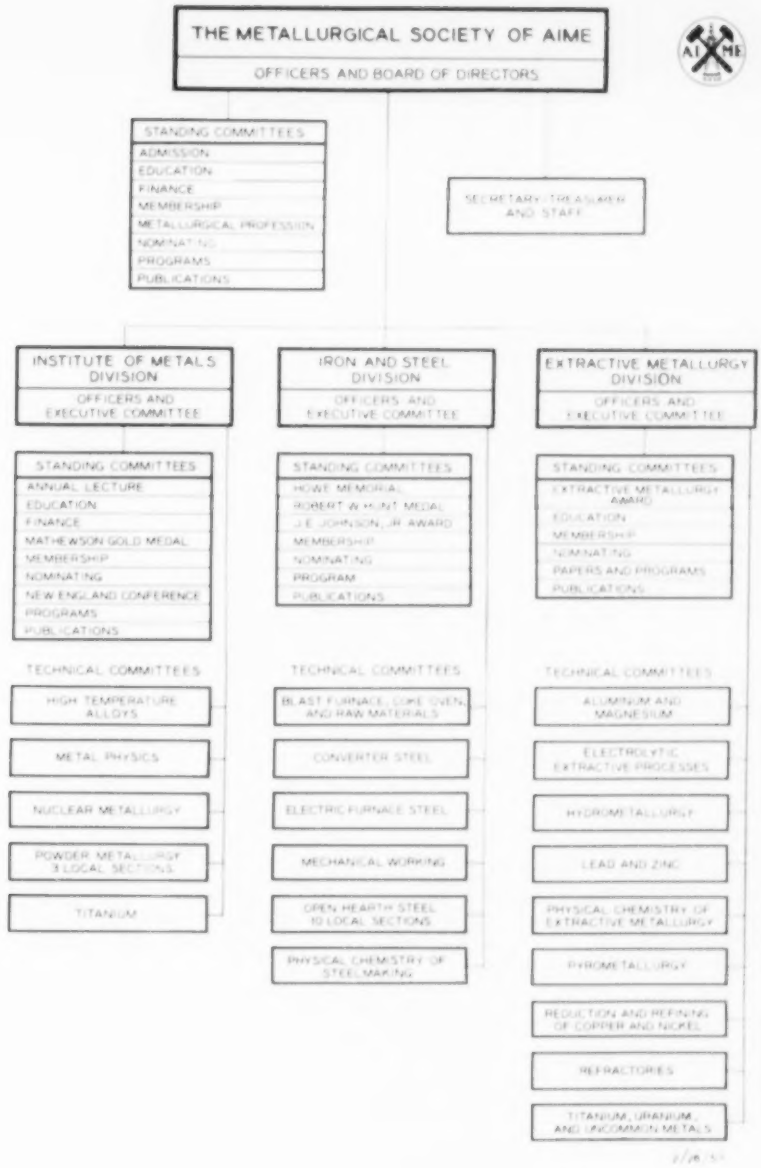
a. President
b. Vice President
c. Past-President
d. Secretary-Treasurer
e. Three representatives from each Division, one of whom shall be Division Chairman, provided that he not be serving as Vice President, President, or Past-President of the Society.

Section 4. The Secretary-Treasurer shall be appointed by the Board of Directors for a term of one year at a salary consistent with his responsibilities, subject to the approval of the Board of Directors of AIME.

Section 5. The Society shall be represented on the Board of Directors of AIME by seven Directors as follows:

a. One member of the Society who will be currently serving as President-Elect, President, or Past-President of the Institute
b. Past-President of the Society
c. President of the Society
d. Vice President of the Society
e. Three Directors, elected for three-year terms
f. Should the Past-President, President, or Vice President of the Society be elected Past-President, President, or President-Elect of the Institute, the Society shall be represented by an additional Director to fill the unexpired term.

Each year, two of the Society's representatives on the AIME Board



of Directors shall be designated as Vice Presidents of AIME, and shall serve for terms of one year each.

For an unexpired term, vacancies shall be filled by appointment by the President of the Society, subject to approval by the Society's Board of Directors.

Section 6. The President-Elect and the representatives of this Society on the AIME Board of Directors shall be nominated and elected as provided hereafter in **Article VIII,** *Sections 1, 2, and 3.*

Section 7. The term of office for officers shall be one year; for other members on the Society's Board of Directors three years; and for Society representatives on the AIME Board of Directors, three years. All terms of office shall start at the close of the annual business meeting of AIME.

Article VI

Divisions

Section 1. The Society shall consist of Divisions as established by the Board of Directors, and initially comprise Extractive Metallurgy, Institute of Metals, and Iron and Steel. A member of the Metallurgical Society may belong to one or more Divisions of the Society by expressing his desire in writing to AIME Headquarters.

Section 2. Each Division shall be governed by its own officers and executive committee, and shall operate under its own bylaws. Bylaws of the Division Executive Committees shall be subject to approval by the Board of Directors of the Society.

Article VII

Committees

Section 1. Standing Committees shall be appointed by the President, subject to confirmation by the Board of Directors at each annual meeting of the Board. In general, appointments shall be made in each case for a specific term of years so that not all terms shall be completed in any one year.

Section 2. Special Committees may be established by the Board of Directors as necessary or desirable. Members of Special Committees shall be appointed by the President, subject to confirmation by the Board of Directors. Special Committees shall be held to a minimum in number, their duties shall be clearly defined, and they shall be dismissed

as soon as their report is accepted.

Section 3. Standing Committees shall be:

a. Finance Committee
b. Programs Committee
c. Publications Committee
d. Membership Committee
e. Education Committee
f. Nominating Committee
g. Committee on the Metallurgical Profession
h. Admissions Committee

Section 4. The President shall appoint at the Annual Meeting of AIME a Finance Committee consisting of three of its members.

The Finance Committee shall prepare the annual budget, and examine, plan for, and submit recommendations concerning the financial condition and welfare of the Society for consideration of the Board of Directors. The Secretary-Treasurer shall not be a member of the Finance Committee, but shall attend its meetings upon the Committee's request, and shall furnish such statements and information as the Committee may desire.

All bills, accounts, and claims against the Society within the approved budget of the year shall be examined and approved by the Secretary-Treasurer of the Society, or such officer or employe of the AIME as its Board of Directors shall from time to time designate.

Section 5. The Programs Committee shall consist of a Chairman appointed by the President and the chairmen of the Division Programs Committees. The Committee shall coordinate program plans and provide for such joint programs among the Divisions as are deemed desirable.

Section 6. The Publications Committee shall consist of at least six members of the Society, two from each Division, appointed by the President. The Committee shall determine publication policies of the Society, shall have authority to accept or reject papers to be published in the publication(s) of the Society, and shall have the duty of preparing and maintaining a publications budget.

Section 7. The Membership Committee shall consist of a Chairman appointed by the President and the Chairmen of the Division Membership Committees, and shall be responsible for the coordination of membership activities.

Section 8. The Education Committee shall be appointed by the President. This Committee shall devise a program to promote high standards in the education of metallurgists and metallurgical engineers, the execution of which is subject to the approval of the Board of Directors.

Section 9. The Nominating Committee shall consist of three members from each Division, selected by each of the Division Nominating Committees, one of whom shall be selected as Chairman by the President.

Section 10. The Committee on the Metallurgical Profession shall be appointed by the President. This committee shall promote high standards in the profession of metallurgy and metallurgical engineering, and shall have the authority to cooperate with organizations having similar objectives.

Section 11. The Admissions Committee shall consist of a Chairman appointed by the President and two members from each of the Divisions of the Society. The Committee shall be responsible for reviewing the qualifications of candidates for membership and presenting the names of recommended candidates through the Secretary, AIME, to the Board of Directors of AIME for approval.

Article VIII

Nominations and Elections

Section 1. The Nominating Committee of the Society shall select:

a. The nominee for Vice President (the President-Elect) of the Society, who automatically becomes a member of the AIME Board of Directors for a three-year term.

b. Every third year, the nominee for President-Elect of AIME, who automatically serves a three-year term on the AIME Board of Directors successively as President-Elect, President, and Past-President.

c. One nominee to serve as Director of AIME for a three-year term.

d. Nominees for Directors of AIME to fill unexpired terms on the Board of Directors should a Director from the Metallurgical Society be selected as President-Elect of AIME or as Vice President (President-Elect) of the Society.

The Nominating Committee shall designate two Society members on the AIME Board of Directors or nominees for the Board of Directors to serve as Vice Presidents of the Institute for one-year terms.

If a previously elected Vice President of the Society should become unavailable for the Presidency of the Society, the Nominating Committee shall also designate a nominee for President.

Section 2. The names and biographies of nominees shall be published in the July issue of the publication(s) of the Society. Any 25 members of the Society may submit additional nominations to the Society's Board of Directors for one or more of the positions specified in **Article VIII,** *Section 1.*

Such nominations shall be submitted not later than August 15 of each year, and notice of the additional nominees for the position designated shall then be published in the October issue of the publication(s) of the Society.

Section 3. If additional nominations are not received by August 15, the President of the Society shall declare the Nominating Committee's nominees to be elected. If additional nominations are received, a letter ballot showing all nominees for the positions designated shall be sent on or about October 1 to all members of the Society in the United States, Canada, and Mexico. The ballots shall be returned within 30 days after they are mailed. The incumbent President shall appoint a Tally Committee to count the ballots, and the nominees receiving the plurality of ballots for each position shall then be declared by the Board of Directors to have been elected.

Section 4. Vacancies in any office of the Society occurring for any reason other than the expiration of term of election shall be filled by the President subject to approval by the Board of Directors.

Article IX

Amendments

Section 1. Proposals to amend these Bylaws shall be made in writing to the Board of Directors of the Society, and signed by at least ten members. These shall be considered by the Board of Directors and announced to the members through the columns of the publication(s) of the Society, together with any comments or amendments made by the Board of Directors thereon. Proposals to amend the Bylaws may also be made by the Board of Directors. They shall be voted on at the Annual Meeting, or other meetings of the Board, or by letter ballot, as may be directed by the Board of Directors. A majority of those voting is necessary to make the amendment. No proposal shall be submitted to members for voting that is inconsistent with the Constitution and Bylaws of AIME.

Section 2. Bylaws and amendments thereto shall be subject to the approval of the Board of Directors of AIME.

Section 3. Proposals to change the decisions, policies, or procedures of the Board of Directors shall be made to it in writing and signed by at least 25 members. Such proposals, unless acceptable to the Board of Directors or withdrawn within 30 days, shall be published with discussion and a ballot in the following issue of the Society journal(s). If it is deemed advisable by the Board of Directors, such proposals may be submitted to the membership in the form of a letter ballot, in lieu of publication, within 120 days after their receipt. The majority of votes cast by the membership in favor of a proposal shall determine that it is adopted.

A Word About the 1957 Nuclear Congress . . .

Late last summer, the National Industrial Conference Board (NICB) decided to cancel its regular Fall Meeting in order to hold the fifth *Atomic Energy In Industry Conference* concurrently with the *1957 Nuclear Engineering and Science Conference*. This brought the element of management into a group which already numbered the leading scientists and engineers, as well as the suppliers, of the fast growing field of atomic energy. The entrance of the NICB was a signal of success to the men who have worked to make the Nuclear Congress a common meeting ground for **all** who have an interest in nuclear science.

The development of this Congress, from its beginnings in 1954, to the meeting in Philadelphia's Convention Hall in March of this year, represents something of a milestone in intersociety cooperation, and it is a tribute to the people who brought it about.

The first meeting of this type was an exposition held in conjunction with the nuclear group of the AIChE, in Ann Arbor, Mich., in June of 1954. Leaders of the various societies realized at this time that this new parameter in engineering and scientific thought was something that pervaded all branches of engineering, and no one society could, or should, claim exclusive dominion over it. Promotion of the idea that nuclear science should be treated by the schools as a part of all engineering curricula, rather than a separate branch of engineering, was also emphasized.

With these goals in mind, a group representing the constituent societies met in August of 1954, and laid the foundations for the first Nuclear Engineering and Science Congress, held in Cleveland in December of 1955, under the sponsorship of the Engineers Joint Council.

Of the many problems confronted in planning this meeting, the inherently secret nature of much of the material, was one of the thorniest. In many cases, by the time information is declassified, it is not **news** in any sense to people in the field. This problem was helped considerably by the formation of the American Nuclear Society, composed entirely of men who have the requisite AEC clearance, and who may consequently discuss matters which are not available to the general public. However, as nuclear science comes more into the public domain, this problem diminishes. At present, the AEC works in close cooperation with the Program Committee for the Congress, with the result that, at least in one case, a paper declassified on one day was delivered by its author on the next.

John Dunning of Columbia University was the general chairman of the 1955 meeting, and D. L. Katz of University of Michigan headed the Program Committee. The success of the meeting was due in no small part to their efforts, along with those of Paul Lange, on behalf of EJC, and the hosting Cleveland Engineering Society.

The 1957 Philadelphia meeting, under the administration of ASME for EJC, can only be termed **bigger and better,** and, as mentioned above, the advent of the NICB brought together, for the first time, all interested groups. Walter Whitman served as Chairman of the General Committee, with Bruce Prentice in charge of the Program Committee. In constant attendance on the floor of the exhibition hall was Tom Marshall of ASME, who served as Congress Manager. Of course, those hours during the actual Congress were nothing compared to the months of work beforehand. Plans for the 1958 meeting in Chicago are presently underway, and it is hoped that it will transcend the idea of concurrent meetings of the several societies and become a truly inter-society affair.

THE 1957 NUCLEAR

The Second Nuclear Engineering and Science Conference, the International Atomic Exposition, the Fifth Hot Laboratories & Equipment Conference, and the National Industrial Conference Board's Fifth Atomic Energy In Industry Conference, were all held under one roof this year, through the coordination of the Engineers Joint Council.

More than 16,000 engineers, businessmen, and scientists attended the 1957 Nuclear Congress, held in Philadelphia's Convention Hall. Sponsored by 25 leading engineering and scientific societies, the week long session was devoted to the peaceful uses of atomic energy. Highlights of the week included major speeches by Kenneth W. Davis and Admiral Paul F. Foster, in charge, respectively, of reactor development and international activities for the AEC. Alfred Iddles, president of the Atomic Industrial Forum and of Babcock & Wilcox Co., read a message from Franz Etzel, vice president of the European Coal and Steel Community and a member of the Euratom Committee. Other speakers included Representative Carl Durham, chairman of the Joint Congressional Committee on Atomic Energy; Carlos A. Bernardes, president of the United Nations' Preparatory Commission, International Atomic Energy Agency; and Robert M. McKinney, editor of the *Sante Fe New Mexican* and chairman of the Panel on Peaceful Uses of Atomic Energy.

Interest in Euratom high

Interest in the development of atomic power in Europe was very high. Several dinner speeches and a session of the NICB Atomic Energy in Industry Conference were devoted to this topic. With electric power costing 10 to 12 mils in many parts of Europe and coal output limited, enthusiasm for a possibly cheaper source of electric power is easy to understand. [Ten days after the conference closed—on March 25th—treaties for Euratom and the European Common Market were signed by the foreign ministers of the six participating countries. This first big step toward a United States of Europe is being built on foundations laid by the European Coal and Steel Community (see JOURNAL OF METALS, October 1956, p. 1458) and is, naturally enough, being watched with great interest on this side of the Atlantic.]

What the well dressed reactor will wear

The second Atomic Exposition might well be described in terms of a fashion show, featuring both the basic designs and the all-important accessories. A stroll through the exhibition hall—it could be done easily in 1½ hr—revealed much of what is *in the air*, as well as the dollar-and-cent facts, of modern reactor technology.

Although some nine different reactor designs are being considered, built, and tested, there seems to be a trend in the thinking that the homogeneous type of reactor will eventually be generally accepted, even though a great deal of development work remains to be done.

The highlight of the pre-convention publicity was the exhibition—for the first time in the U. S.—of an operating nuclear reactor. Built by Aerojet-General

CONGRESS

Nucleonics, it was, perhaps, indicative of the age we are about to enter into, in that it was completely unspectacular! Although the harnessing of the energy of the atom is something which sends the imagination soaring into the realms of space and time, the actual manifestation is nothing that will ever excite a small boy. No pistons, no shafts, no smell of oil or gasoline, no clouds of smoke and steam—in fact, the only moving thing is a needle on the dial of the control console. The main features of the powerhouse of tomorrow will evidently be a hospital-like cleanliness and a pervading silence.

Not that operation of a reactor can not have its exciting moments—this was amply demonstrated by the Leeds & Northrup simulator, which took one from the preliminary steps of bringing the reactor up to *critical*, to an emergency *Scram*. It was well done and drew large crowds.

A nuclear battery was exhibited by the Walter Kidde Laboratories. Using a β-emitter to light a CdS phosphor which a photocell turns into electricity, the battery is soon to appear in an Elgin watch.

Literally a high spot of the exposition was the 22-ft tall vacuum arc furnace featured by National Research Corp. The unit has a capacity of 100 lb of steel and is one of many pieces of high vacuum equipment produced by NRC.

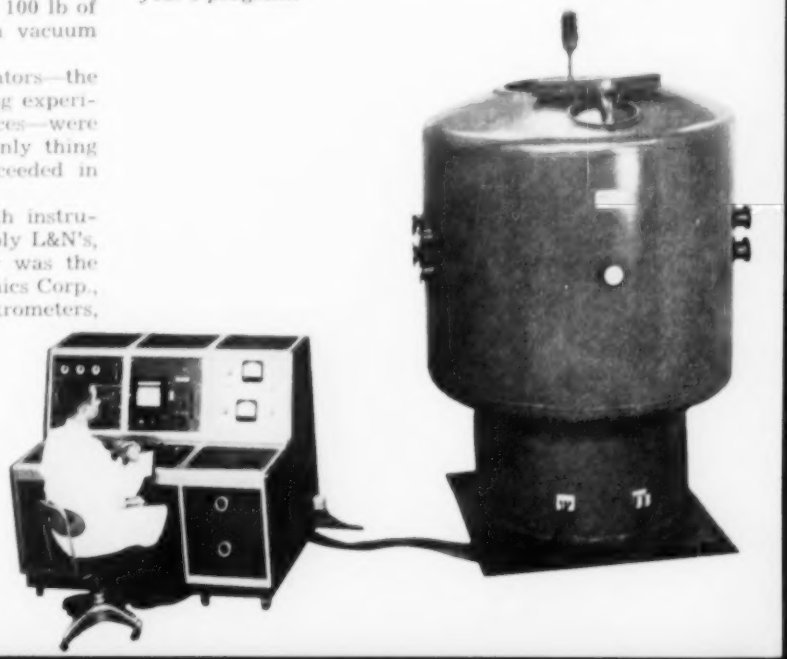
Hot laboratory master-slave manipulators—the mechanical hands necessary for performing experiments with highly radioactive substances—were popular as *do it yourself* exhibits; the only thing lacking was a prize for those who succeeded in threading a needle with the machines.

The majority of the exhibits dealt with instrumentation—the most complete was probably L&N's, mentioned above,—but the most popular was the very modest booth of the Nuclear-Electronics Corp., which, in addition to scintillation spectrometers, featured a blonde and a brunette, both of whom were, it was agreed, scintillating. Their limited knowledge of the equipment seemed to disturb very few visitors.

Technical program covers all phases

The technical program, certainly the heart of any meeting of this type, consisted of over 200 papers and panel discussions covering all phases of nuclear science that have been declassified by the Government. These papers are available in separate copy form for $0.30 each. Orders must be by paper number, and should be addressed to ASME Order Dept., 29 W. 39th St., New York 18, N. Y.

John Landis, 1958 Program Chairman, cautions authors that they must send abstracts to their societies by July 15, 1957, for consideration on next year's program.



The Aerojet-General-Nucleonics 201 nuclear reactor, shown at right, was the first operating critical reactor to be exhibited in the U. S. Operating at a power of 100 milliwatts, the completely safe reactor has many applications in education, training, and research.

BLAST FURNACE
U.S.A.

I. Colonial Ironmakers

Blast furnaces are the tools of men, and it is men who have made them great. Here is presented the story of the Ironmakers—the men who first poured hot metal into what would someday be the sinews of a nation.

by M. O. Holowaty and C. M. Squarcy

WHEN the Jacobean merchant adventurers bade farewell to the first ship of colonists sailing for the *new land*, they instructed them to direct all their skill and energy to grow silk worms in Virginia. The adventurers felt sure that they could flood the market with highly priced and much desired goods like silk, sugar, tea, and indigo. They were also convinced that they would fill the needs of the *mother country* for iron.

Early iron production in the colonies

The merchants certainly had a wonderful imagination, for silk and indigo were just as exotic in Virginia as they were in England. The settlers found it more profitable to raise tobacco on the vast stretches of the free, fertile land. Thus the plans of settlers clashed with those of The Virginia Co.; and only point of agreement was the desire to produce iron. But, even there the motives of the settlers and those of The Virginia Co. of London were worlds apart. The settlers wanted to produce the tools badly needed in the colony, while the Company desired to cash in on the rising demand for iron which the home industry could not satisfy.

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Both the settlers and the Company lost no time trying to find iron ore. Locations of the early mines are not known. If, however, the reports of the Irishman, Francis Maguel, can be trusted, as early as 1609 a ship sailed for England with a load of 17 tons of crude iron which the East India Co. purchased at £4 per ton. The iron was of excellent quality and considered the best iron made of non-English ore that was ever purchased.

Colonial forges and charcoal blast furnaces

Forges were reported to be quite common during the first years of white man's existence in North America. During the first three years after the founding of Jamestown, machinery had already been erected by settlers who worked the iron mines. It is also known that many small implements were made by the colonists from iron which was produced in local forges or in Catalan forges.

The Massachusetts Bay Colony boasted a number of them during the second half of the 17th century. Bloomery forges of 200 to 400 lb capacity were operated at Mendon, Harvard and Westin. A large bloomery was located at Northborough, famous for a short time for its cast iron pottery and stoves.

An integrated iron works at Westminster supplied slit bars and rods for making tools and implements for the farmers, while the rod and nail mill at Wachusett excelled in spikes, nails, and axes.

The forges stood their ground in the age of the charcoal blast furnace, and began only a gradual retreat in the era of anthracite. Almost all forge plants were established on the basis of home industries and were operated to satisfy local needs. Iron as such was not exported in any quantities to either England or to other countries.

Falling Creek starts as religious venture

In 1619, an anonymous contribution of £500 was made to the Virginia Co. for the distinct purpose of promoting conversion of Indian children living in the colony to the Christian faith. The colonists decided to establish an industry whose profits would be used for the conversion work instead of spending the money directly. Their plan was to multiply the original sum through the growth of the iron industry. They added £3500 to the original contribution and contracted for iron works to be built in Virginia as soon as possible. The profits were to be used in instructing 30 Indian children in the doctrines of the Christian church. Thus, the Southampton Adventurers intended to accomplish two purposes: promotion of the economic welfare of the colonies and the conversion of the Indian tribes to Christianity.

Subsequently, the steering committee of the Adventurers addressed a letter to Yardley, who was governor of Virginia and captain of the Southampton Hundred. In this letter Yardley was urged to show utmost care in setting up the project "as upon these works were fixed the eyes of God, angels and men." The London office acted quickly upon Yardley's request, and dispatched Capt. H. Blewit with a group of 80 skilled iron workers to Virginia in the spring of 1621.

Captain Blewit died shortly after reaching Jamestown, but he was quickly replaced with John Berkeley of Gloucestershire. Work on the iron plant started in the fall of 1621 at the location known as

Falling Creek, about seven miles below the falls of James River. The site had been suggested by Sir Edwin Sandys who also made the original cost estimate of £4000. In making this suggestion he had in mind the proximity of all required raw materials, timber, ore, limestone, water, and also sandstone for the construction of the blast furnace itself.

In February of 1622, Berkeley reported to the Society in London that the blast furnace was just about completed and he expected to make iron very cheaply. The trustees of the company, already in high spirits over the success of the venture, voted to meet their manager's expenses whatever they might be. They did not even dream that on the very day of their voting, Mar. 22, 1622, their men were being murdered and their enterprises destroyed by savage Indians. Only two people escaped the Indian massacre at Falling Creek, a boy and a girl who hid in the bushes. Berkeley, his family, and his workers were murdered ruthlessly without apparent motive or provocation. The tools and the furnace machinery were broken up and tossed into the river.

The real tragedy of Falling Creek was in the annihilation of the iron makers. Judging from the speed with which the plant was built, they were undoubtedly masters of the profession. The colonies recovered quickly from the material loss, but the shortage of skilled men delayed establishment of a successful domestic iron industry for many years to come.

The news of the massacre at Falling Creek shocked the colony, the London offices of the Virginia Co., and even the Royal Court, but it did not diminish the interest in establishing the iron industry in the colonies. More ironmakers were contracted to go to Virginia in early 1623, to repair the damages and put the furnace in operation.

After the accession of Charles I to the English Throne in 1625, the king revoked the charter. Several attempts were made to interest the young monarch in establishing the industry in Virginia, but Charles saw a quicker road to fill his treasure by imposing enormous and unheard-of domestic taxes. King Charles intended to establish a number of royal industries in the colonies. He sent William Capes to Virginia in 1627 or 1628 with a commission to establish a number of industries, including the manufacture of iron. In spite of the great support of the governor and the Burgesses, Capes quickly antagonized colonists and was forced to leave the country before any of his plans could materialize.

Sir Isaac Zouch and his son almost succeeded in reestablishing the Virginia iron industry in 1635. Proceeding on their own they rebuilt part of the machinery of the Falling Creek plant, but were forced to give up because of lack of funds. This was apparently the last attempt to produce iron in early Virginia. In the closing years of the 17th century, Falling Creek was just another forgotten place in the wide open spaces of the *New World*.

The Spotswood furnace at Germanna in Virginia, 1716

One morning in the summer of 1710, a new ship landed at Jamestown, Va. Aboard the ship, was the new lieutenant governor of the colony, Colonel Alexander Spotswood. Spotswood was born of Scotch parents in 1676 at Tangier, at that time a British possession. Raised outside England, he developed an organizational talent to work with people of other nationalities, a foresight and understanding which were rare in his day. As governor of Virginia, he proved to be a brilliant and far-seeking statesman.

Shortly after his arrival, Spotswood was approached by Baron Christopher de Grafenreid, a prominent Swiss landowner who had led a group of his countrymen and Germans to North Carolina. There was talk in 1712 about silver ore in the Massanutten Mountain, and Spotswood and Grafenreid discussed it many times. It was decided that the latter would go to Europe and search for miners.

In the spring of 1714, 40 German miners from the Sieg Valley arrived in Virginia. Spotswood, who paid for their passage settled them permanently along the northwestern frontier. The location was named Germanna, and the place was fortified with a blockhouse and two cannons. Spotswood petitioned London for permission to mine silver, but until the royal sanction was obtained the German settlers had to remain idle. Soon they found outcrops of iron ore and attempted to interest their protector in an iron venture.

In September 1716, the governor decided that iron mining was better than doing nothing, and took out a land patent for 3229 acres in the name of William Robertson, recorded as being in Essex County, in the parish of St. George, approximately 20 miles above the falls of the Rappahannock River. The land patent incuded Germanna and the surrounding country, rich with ore beds and vast timber reserves. The Spotswood blast furnace was built in 1716 or 1717. The exact date is not known but can be deduced from complaints made to the crown about Spotswood's activities during that time.

Spotswood also had his defenders, but the perseverance of his enemies bore fruit, and, after serving 12 years as governor, Spotswood was removed in 1723. He was well provided financially; he owned about 65,000 acres of land, two blast furnaces, an iron bloomery, hemp fields, and plantations. Rather than return to England, Spotswood decided to throw in his lot with the new country and spent the remaining 18 years of his life developing frontiers and, according to his critics "squeezing out his partners from land tracts and enterprises."

The dimensions of the principal blast furnace at Germanna are not known, but judging from the annual average production of 800 tons, it can be assumed that it measured 6 to 7 ft across the bosh. Thus, Spotswood was the first to inaugurate the iron industry in Virginia and to operate a blast furnace exclusively producing pig iron on the American continent.

After several of his original German workers left him, Spotswood decided to run the enterprise with slave labor. To the visiting nobleman, Colonel William Byrd, he explained that except for raising ore and running the blast furnace, he employed solely slave labor. Byrd found that from 100 to 120 slaves were required to run the furnace, including women to cook and farm hands to raise corn and cut hay for feeding the oxen, needed for hauling charcoal and iron ore.

In 1724 a group of English iron masters formed the Principio Co. of Maryland, and blew in a blast furnace in 1725. Soon, however, this young enterprising company extended its interests to Virginia and built a blast furnace at Accokeek on the property belonging to Augustine Washington in Stafford County. Two years later, the stock of the Accokeek

plant was valued at £3000, including raw materials, plant facilities, and slaves. Colonel Byrd visited all iron plants of Virginia in 1732; the same year Augustine Washington became the father of a son named George.

Byrd's observent eye caught the features of the Spotswood furnaces, while his keen mind quickly evaluated the problems of ironmaking in the new country. He wrote:

"We proceeded to the furnace, which is built of rough stone, having been the first of that kind erected in the country. Here the wheel that carried the bellows was no more than twenty feet diameter; but was an overshot wheel that went with little water. This was necessary here, because water is something scarce, notwithstanding it is supplied by two streams, one of which is conveyed one thousand and nine hundred feet through wooden pipes, and the other sixty . . . The name of the founder employed at present is one Godfrey—whose wage is three shillings and six-pence per ton for all the iron he runs, and his provisions . . . He complained that the colonel starves his works out of whimsicalness and frugality, endeavoring to do everything with his own people, and at the same time taking them off upon every vagary that comes into his head . . .

"Another newer furnace of Spotswood's is elegantly built of brick, though the hearth be of firestone . . . (The) operator looked a little melancholy, because he had nothing to do, the furnace having been cold ever since May, for want of corn to supply the cattle . . . But having received a small supply they intended to blow very soon. With that view they began to heat the furnace, which is six weeks before it comes to that intense heat required to run the metal in perfection. Nevertheless, they commonly begin to blow when the fire has been kindled a week or ten days. Close by the furnace stood a very spacious house full of charcoal, holding at least four hundred loads, which will be burnt out in four months. The fire in the furnace is blown by two mighty pairs of bellows, that cost one hundred pounds each, and these bellows are moved by a great wheel of twenty-six feet diameter. The wheel again is carried round by a small stream of water conveyed about three hundred and fifty yards over land in a trough, from a pond made by a wooden dam. But there is great want of water in a dry season, which makes the furnace often blow out, to the great prejudice of the works.

". . . We took a walk to the principal mine, about a mile from the furnace, where they had sunk in some places about fifteen or twenty feet deep. The operator, Mr. Gordon, raised the ore, for which he was to have by contract one and sixpence per cartload of twenty six hundred weight . . . The rate of twenty five shillings a month, and for all that was able to clear forty pounds a year for himself. We saw here several large heaps of ore of two sorts, one rich and the other spongy and poor, which melted together to make the metal more tough. The way of raising the ore was by blowing it up, which operation I saw from beginning to end. They first drilled a hole in the mine, either upright or sloping, as the grain of it required. This hole they cleansed with a rag fastened to the end of an iron with a worm at the end of it. Then they put in a cartridge of powder containing about three ounces, and at the same time a reed full of fuse that reached to the powder. Then they rammed dry clay, or soft stone very hard into the hole, and lastly they fired the fuse with a paper that had been dipped in a solution of saltpetre and dried, which burning slow and sure, gave leisure to the engineer to retire to a proper distance before the explosion. This in the miner's language is called making a blast, which will loosen several hundred-weight of ore at once; and afterwards the laborers easily separate it with pickaxes and carry it away in baskets up to the heap. At our return we saw near the furnace large heaps of mine with charcoal mixed with it, a stratum of each alternately, beginning first with a layer of charcoal at the bottom. To this they put fire, which in time spreads through the whole heap, and calcines the ore, which afterwards easily crumbles into small pieces fit for the furnace. There was likewise a might quantity of limestone brought from Bristol, by way of ballast, at two and sixpence a ton, which they are at the trouble to cart hither from Rappahannock River, but contrive to do it when the carts return from carrying of iron. They put this into the furnace with the iron ore, in the proportion of one ton of stone to ten of ore, with design to absorb the sulphur out of the iron, which would otherwise make it brittle. And if that be the use of it, oyster shells would certainly do as well as limestone, being altogether as strong an alkali, if not stronger. I observed the richer sort of mine, being of a dark color mixed with ruts, was laid in a heap by itself, and so was the poor, which was of liver or brick color. The sow iron is in the figure of a half-round, about two feet and half-long, weighing sixty or seventy pounds, whereof three hundred weight make a cartload . . . When the furnace blows it runs about twenty tons of iron a week. The founders find it very hot work to tend the furnace, especially in summer, and are obliged to spend no small part of their earnings in strong drink to recruit their spirits. Besides the founder, the collier, and miner, who are paid in proportion to their work, the company has several other officers upon wages, a stock-taker, who weighs and measures everything; a clerk, who keeps an account of all receipts and disbursements; a smith to shoe their cattle and keep all their iron work in repair; a wheelwright; cartright; carpenter; and several carters. The wages of all these persons amount to one hundred pounds a year; so that including Mr. Chiswell's salary, they disburse two hundred pounds per annum in standing wages . . .

"Col. Spotswood told me he had iron in several parts of his great tract of land, consisting of forty-five thousand acres. But that the mine he was at work upon was thirteen miles below Germanna . . .

"The Colonel has a great deal of land in his mine tract exceedingly barren, and the growth

of trees upon it is hardly big enough for coaling . . . All the land hereabouts seems paved with iron ore; so that there seems to be enough to feed a furnace for many ages."

Byrd seems to have been very much interested in the "art of iron making," for he spent some time with Mr. Chiswell, Manager of the Germanna furnace, inquiring about the details of operation. Chiswell assured him

"that the first step I was to take was to acquaint myself fully with the quantity and quality of my ore. For that reason I ought to keep a good pick-axe man at work a whole year to search if there be a sufficient quantity, without which it would be a very rash undertaking. That I should also have a skillful person to try the richness of the ore. Nor is it great advantage to have it exceedingly rich, because then it will yield brittle iron, which is not valuable. But the way to have it tough is to mix poor ore and rich together, which makes the poorer sort extremely necessary for the production of the best iron. Then he showed me an example of the richest ore they have in England . . .

"He told me, after I was certain my ore was good and plentiful enough, my next inquiry ought to be, how far it lies from a stream proper to build a furnace upon, and again what distance that furnace will be from water carriage; because the charge of carting a great way is very heavy, and eats out a great part of the profit. I was in the next place to consider whether I had woodland enough near the furnace to supply it with charcoal, whereof it would require a prodigious quantity. That the poorest wood for that purpose was that of oily kind, such as pine, walnut, hickory, oak, and in short all that yields cones, nuts, or acorns. That two miles square of wood supply a moderate furnace; so that what you fell first may have time to grow up again to a proper bigness (which must be four inches or over by that time the rest is cut down.

"He told me further, that one hundred and twenty slaves, including women, were necessary to carry on all the business of an iron work, and the more Virginians amongst them the better; though in that number he comprehended carters, colliers, and those that planted the corn. That if all these circumstances should happily concur, and you could procure honest colliers and firemen, which would be difficult to do, you may easily run eight hundred tons of sow iron a year."

Only a few miles away from Germanna, Byrd inspected an air furnace or a bloomery which was also owned and operated by Spotswood. The blast furnaces were idle at the time of the visit. The Germanna furnace was down for repairs, and the Fredericksville furnace, which during the preceding year produced 1200 tons of iron, was down temporarily for lack of feed for the oxen. This eventually proved to be the main reason for abandoning the Fredericksville furnace in 1735 or 1736.

Alexander Spotswood died in 1740 without leaving an heir. He was followed closely by Augustine Washington. For a while their works lived after them, Augustine Washington's place on the board of the Principio Co. fell not to the 11-year-old George, but to his half brother, Lawrence, from Augustine's first marriage with Jane Butler.

In 1750 Virginia and Maryland together exported to England about 2460 tons of pig iron. One sixth of this supposedly came from the Accokeek furnace. However, after the death of Lawrence Washington in 1753, the Principio Co. moved all its stock and men to Maryland. The Germanna furnace was still active in 1750 when 410 tons of Germanna pig iron were sent to England. Since no further information could be found in the literature, it can be assumed that it ceased to operate shortly after 1750.

There are no ruins left of any of the Spotswood furnaces. Mr. H. W. Johnson, who visited the site in 1936, found only a steel signboard which read:

"Spotswood's Furnace

Four miles north on this side road is the site of an ancient iron furnace, established about 1716 by Governor Alexander Spotswood, the first fully equipped furnace in the colonies. Iron was hauled along this road to the Rappahannock River for shipment. William Byrd visited the furnace in 1732 and described it."

Johnson adds, "If you turn down the side road, you find the ground more uneven than along the highways, a scrub growth borders the road, interrupted only here and there by a wagon road or a shack. The road has recently been improved and covered with a layer of gravel, which on examination looks very much like broken blast furnace slag . . ."

The Principio Co., established in 1714 to produce iron in Maryland

The British custom officers did not believe their eyes—the ship that just arrived brought a load of iron bars from American consigned to Joshua Gee of Shrewsbury and William Chetwynd, Esq., of London. The year was 1718 and the shipment was small—only 3½ tons, but nevertheless, it was there and was probably just the beginning of what eventually would pour from the colonies. The custom officers were right—for the flow of the iron from the colonies increased considerably during the next decade, especially so from one iron works, the Principio plant of Maryland.

The Principio Co. had its beginning in England. In 1714, a group of businessmen headed by the brothers Joshua, Samuel, and Ozgood Gee; William Chetwynd; and Sir Nicholas Carew, decided to venture into production of iron in the colonies to supplement the diminishing production and the increasing need for iron in the mother country. The undertaking seemed promising enough—if Capt. John Smith, who in 1606 reported iron ore in the Chesapeake Bay area, could be trusted. In any case, it appeared worthwhile to dispatch Mr. Joseph Farmer to the new country, with the instructions to decide if and where to build the iron works.

Joseph Farmer arrived in New Castle in the spring of 1715, and began immediate inquiries about the iron industry of the new colonies. He was informed about the earliest furnace at Falling Creek, which could be reconditioned and put in operation. He also heard the stories about John Winthrop's iron ventures at Saugus and Braintree, and their rather indifferent success. The Winthrop furnaces were down completely and the Philadelphia Quakers strongly advised Farmer against New England, which had only bog ore, and even that was low in iron and quantity.

There were rumors about bloomeries and forges in Maryland, and Farmer decided to follow these up because of Maryland's proximity to the open waters of the Atlantic Ocean and thus to England. Exploring for a blast furnace location, the English ironmaster rode along the Back Creek, which for some reason fascinated him. Farmer could perceive the sound of falling water, and forcing his way through a virtual jungle, he faced a waterfall. Excited by this find, he rode down the river looking for iron ore which was reported by Captain Smith. The deepening water forced him to take to the red river bank and here to his happiness he found what he was searching—lumps, chunks, and granules of grayish iron ore.

The only thing that troubled him was whether the Back Creek connected to Chesapeake Bay. Pushing further down the river, Farmer suddenly realized that just ahead of him was the smooth and calm surface of the mighty Bay. The way for the construction of the blast furnace was clear, and Farmer hurried back to his tavern headquarters to report the findings to his friends.

Farmer obtained a lease on the Back Creek land from the Lord Proprietary of Baltimore, who was extremely anxious to obtain settlers for his crown land.

The shortage of labor was very serious. African Negroes were hard to get, and the Indians did not stay on the job. Hoping to get assistance, Farmer set out to Philadelphia. Labor problems here were just as bad as near the Back Creek, but a Quaker friend advised Farmer to get a regular blast furnace crew from England. He wrote a letter to his British partners, requesting them to send to the colonies a group of 20 to 30 indentured workmen from the English prisons. About six months later, Stephen Onion and the brothers William and Thomas Russell, brought a group of some 20 workmen whom they placed at the disposal of the Principio's master.

Construction started almost immediately, but the work progressed slowly. The workers were not happy with their lot and spent most of their meager wages on rum, which was plentiful and cheap in the colonies.

The construction of the stack was started in the fall of 1720, but the shortage of suitable sandstone for the structure of the furnace made the work exceedingly slow. By 1722, the letters of Farmer to his masters in England grew more and more flowery, but there were no shipments or iron outside the 3½ tons of forged bars produced in 1718. Farmer arrived in London late in 1722, and gave an enthusiastic account of his accomplishments. This made the financiers of the Principio project even more suspicious and they decided to have an impartial expert, John England, investigate the entire matter.

Although John England was received with cordiality by Stephen Onion and William and Thomas Russel, they departed shortly for England, without accounting for the company's expenditures and the stock of the Principio plant. Both were in a sad state. In his report to London, John England complained bitterly about almost everything he found in Maryland, particularly the financial situation and the crew which was just about ripe for rebellion.

Inspection of the company-owned lands showed some to be entirely worthless. Investigation of the company finances disclosed that the treasurer, Stephen Onion, had used the money for his private deals, and mismanagement in the charcoal-making operation had almost doubled the price of this material. During the summer of 1723, England tried to bring the company business in order and periodically reported what little progress there was to London. The workmen were somewhat calmer now but occasionally England had to prove his superiority by sheer physical strength. His homelife was shattered when his wife died of homesickness in the early fall of that year. The outlook was indeed black—and yet, John England stuck to his young plant.

Gradually the situation improved. John England was declared the sole master over the company's entire operations in America. Starting just above the level of the two tuyeres, where Farmer left off, England's masons were now speedily finishing the construction of the Principio furnace.

Shaping of the interior was his personal concern. The furnace bosh, very carefully lined, widened rapidly a short distance about the hearth, to form a huge belly to hold charcoal, ore, and fluxes.

In the fall of 1724 the furnace was blown in. Right from the beginning, Principio iron flowed to Liverpool and Birmingham where it was sold at a most favorable price. However, the Principio Company was by now not only an iron plant but also boasted a complete plantation raising its own wheat, cattle, and vegetables, maintaining its own stores. The fame of the Principio Works and its manager spread quickly throughout the colonies and even Europe, with the result that many an ironmaster came to work for John England of Maryland.

A year after blowing in the Principio furnace, John England proposed to his British associates an expansion of the operations into Virginia. There, he wrote to London, were large deposits of good ore and extensive supplies of charcoal timber. He even selected the land which appeared most promising for the construction of a blast furnace—the property of Captain Augustine Washington. John England visited Captain Washington at the latter's Pope Creek home and proposed a partnership according to which Captain Washington would own two twelfths of the new plant while the rest would be divided among the English partners of the Principio Co., including John England. Captain Washington also contracted to haul iron ore to the furnace at the fixed fee of 20 shillings per ton of contained iron.

In the summer of 1726, the blast furnace on Washington's land was blown in and named Accokeek, which was the name of an Indian chief befriended by Washington.

Iron production of the Accokeek furnace exceeded the most enthusiastic expectations of the Principio Co., averaging from 40 to 50 tons per week. Both the Principio furnace and the Accokeek furnace became the center of attraction of the iron men from the colonies and the European countries.

The greatest tribute paid John England was by a man who had never seen the Principio installation; Emanuel Swedenborg, in his celebrated book *De Ferro* called Principio iron the best man ever made. John England was old by now, with hollow cheeks, and a long, patriarchal beard. De Ferro's remarks were almost like an obituary, for John England died only a few weeks later, in the autumn of 1734.

The second part of *Blast Furnace U.S.A.* will appear in a forthcoming issue of the JOURNAL OF METALS.

Background of Government-Sponsored Research

The decades following the organization of the AIME in 1871 trace a vitalized Government interest in science to publicly dedicated men of science from whose work emerge three organizations that are equally important today — the Coast and Geodetic Survey, the Smithsonian Institution, and the U. S. Naval Observatory.

Summarized from an article by Lawson M. McKenzie

BEFORE the Civil War, the Coast Survey, the Smithsonian Institution, the Agriculture Div. of the Patent Office, and the Naval Observatory were the four agencies through which the Government was involved in science.

The Coast Survey: Jefferson in 1807, under the influence of the American Philosophical Society, secured a Congressional appropriation of $50,000 to begin a coast survey. Based upon defense needs, the act called for a complete survey of the coastal waters of the U. S. In 1844 the difference in longitude between Europe and the U. S. was still uncertain, and the second head of the survey enlisted astronomers who were paid small sums for copies of their observations. The work of the Survey was extended to the interior in 1878 under the name of the Coast and Geodetic Survey.

The Survey was early responsible for distribution of standards and carried out experiments on the accuracy and construction of standard bars. By 1897, the weights and measures department was under the charge of a field officer who had two scientific assistants: an instrument maker and a messenger. A University of Chicago physics professor, S. W. Stratton, was appointed that year, and in 1901, when the function was transferred to a new Government agency, he became the first director of the National Bureau of Standards.

Early scientific activities of the Navy: The U. S. Naval Observatory had its origin in an office established in 1830 for the care of instruments and charts of the Navy. To rate chronometers, the officer in charge acquired a transit instrument. His successor in 1833 erected, at his own expense, a 16-ft square building to mount a 5-ft transit loaned by the Coast Survey—the first Naval Observatory. Later, the bureau expanded its activities by acquiring magnetic and meteorological instruments and additional assistants. It was formerly organized in 1842 by Congressional act, and a building program began.

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Lt. Mathew F. Maury was appointed superintendent in 1844 and immediately widened the scope of the observatory by analyzing oceanographic data from ships logs prepared according to his specifications. From 1844 to 1861 he issued wind and current charts from his Hydrographic Office.

In 1862 Adm. C. H. Davis, who founded the Almanac Office separately but under Lt. Maury's administrative supervision, was appointed the first Chief of the Bureau of Navigation. The original plan was to bring under one head all scientific departments of the Navy related to hydrography, astronomy, navigation, and surveying, and to include the Nautical Almanac, the Observatory, and the Naval Academy. Adm. Davis proposed a permanent commission to advise the Navy Department on scientific matters. The plan received the prompt attention of the Secretary of the Navy, who issued an order on Feb. 11, 1863 creating the *Permanent Commission*.

While awaiting the result of the Navy Department's consideration of the plan to establish a scientific commission, the idea occurred to Adm. Davis that an Academy of Sciences might be organized by simply asking Congress for its incorporation. Others had conceived of the need for "an institution of science supplementary to existing ones to guide public action in reference to scientific matters." A bill of incorporation of the National Academy of Sciences was passed and signed.

Smithsonian Institution: The story of the origin of the Smithsonian Institution was in sharp contrast to that of the Academy. After accepting a bequest of over a half million dollars of James Smithson in 1830, Congress procrastinated for eight years before acting in 1846 to establish the Institution. Under the leadership of Joseph Henry, the first Secretary, the Smithsonian became the leading organization for 19th Century American science. A private foundation, although ward of the Government, it became connected with many important scientific undertakings for the Government.

The Smithsonian had been involved in meterology since its founding. Weather data was collected there by telegraph from 1849 to 1870. The Smithsonian began to compile maps about 1851 and to display

them to the public after 1856. In 1870 the Weather Bureau of the Signal Corps assumed the work begun by the Smithsonian.

Patent Office: Jefferson's deep thinking about the nature of mechanisms and patents thereon led to the present American patent system which, from The Act of 1836, had no counterpart in the world at that time. It was altogether different from the British, French, and other systems. Under this American institution, afterwards copied by the Germans and in later years by the British, a search was required to determine whether the applicant was entitled to a patent.

The Twentieth Century

The *Permanent Commission* of 1863 consisted of three men: one from the Bureau of Navigation, one from the Smithsonian Institution, and the third from the Coast Survey. In 1915 the Secretary of the Navy invited Thomas A. Edison to act as chairman of a Naval Advisory Board of 24 men. Eleven engineering societies were requested to select two of their members to serve on the board. Some were appointed, others elected to represent the societies—for example, the AIME Board of Directors selected by ballot W. L. Saunders and B.B. Thayer.

The Board was particularly active in calling attention to industrial preparedness and paved the way for the creation of President Wilson's Council of National Defense. The Board later served the Council as an Inventor's Council. The National Research Council (NRC) was organized by the Academy of Sciences in 1916 as an arm of the Council of National Defense and was formalized by Executive Order in 1918 under which it operates today. The NRC served as the Department of Science and Research of the Signal Corps, and it established a research information service with attachés in London and Paris.

Upon recommendation by the Naval Consulting Board, a million dollars was appropriated in 1917 to launch the Naval Research Laboratory. This laboratory and the Engineering Experiment Station in Annapolis, the aircraft factory, Dahlgren Proving Ground, the powder factory, the small ordinance laboratory, and the model basin in the Washington Navy Yard were the start of the fifty-odd naval laboratories that now exist and employ nearly 10,000 scientists and engineers.

Although we have restricted ourselves to the expanding Navy scene and fragmented one to boot, such expansion is typical of the Federal enterprises generally.

Place of science today in the Federal Government

In considering the place of science today in the Federal Government, it is necessary first to get some idea of the size of the problem. The U. S. Government employs about 37,500 scientists and engineers in purely scientific activities. Although this number represents but 6 pct of the estimated scientific population of the Nation, a review of Government support of university and industrial activities indicates that a far greater number are involved in Government work. Thirty seven percent of the amount spent by private industry on scientific research represents work done for the Federal Government, about 1.5 billion dollars. In addition, Government provides some support for 345,000 undergraduates and 43,000 graduate students.

Over the last two decades there has been a sharp increase in Federal employment of scientists and engineers. Between 1931 and 1954 the increase was sevenfold. Between 1947 and 1954 the increase due to World War II activities is readily understood. The lesser increase since then apparently represents a tapering off to a new norm in the Government's dependence upon science, for it seems that its machinery for use of science is roughly complete—at least at the present plateau of National development.

Defense, exploitation of natural resources, agriculture, and commerce are areas which involve most of the Government's scientists—and in this order. The Department of Defense employs 68.3 pct of the Government's scientists; the Department of Interior, 7.4 pct; the Department of Agriculture, 6.1 pct; and the Department of Commerce, 5.9 pct.

Of these employes a considerable number are involved in planning and administering this research and development—nearly 2000. Upon this 5 pct of the Government's scientific staff depend such matters as: a) the coordination of the multibillion dollar enterprise, b) responsibility for acquisition and distribution of the funds, and c) for the quality of the programs.

Advisory and coordinating committees: Within the present Government machinery for scientific research are a number of inter and intra departmental coordinating committees. One of the more important of these is the Interdepartmental Committee On Scientific Research and Development (ICSRD). An important feature of the complex of committees are interlocking memberships between them. They are not necessarily organized this way, but the common membership provides a superb means of coordinating the work between the agencies.

There are also a great number of public advisory committees. A recent survey of the House Committee on Government operations resulted in a catalog of seven volumes comprising 3478 pages describing them. The preface of this report explains: "The advisory committee is not a new device in Government. In working as a part of a diversified and complex economy, Government agencies have shown a growing tendency to make use of the advisory committee in one form or another."

Offices devoted to fundamental research: Paralleling the spread of advisory committees has been the rise of offices devoted to more or less fundamental research. Again, these are not new, but their scope and numbers are larger than heretofore.

Charting the way was the Office of Naval Research, created by law in 1947 following its establishment in 1945 as the Office of Research and Inventions. This office took over control of the famous Naval Research Laboratory and the war-born Special Devices Center. It subsequently built up a substantial program of contract research, mainly with universities, and programs identified as Naval sciences.

Reflecting this pattern of support of agency research objectives by way of contracts, especially with universities, are: the Research and Development Div. of the AEC formed as one of the five divisions of the new AEC in 1947, the office of Scientific Research (now of the Air Research and Devel-

opment Command) established in 1948 in the Air Materiel Command, and the office of Ordnance Research organized in 1952.

Contractor-operated research centers: A third *new* aspect of today's machinery to do Governmental research and development work is the contractor-operated research center. Argonne, Oak Ridge, and Brookhaven are now three of America's great laboratories. Equally prominent are several Defense Department Centers, such as the Lincoln Laboratory of MIT, the Operations Research Office (Army) managed by the Johns Hopkins University, and the RAND Corp. (Air Force.)

To recapitulate: a) Contractor-operated research laboratories, b) offices especially created to contract for research in support of the mission of an agency, and c) the advisory committee complex are today recognized as three highly important devices for conducting and coordinating the Federal Government's research and development effort. These peculiar fundamental features of present day organization of *Federal* science have been historically produced. The Longitude Department of the Coast Survey and the Nautical Almanac Office of the Navy are early examples of important Government activities organized at seats of special competence. Payments to astronomers in connection with the Coast Survey is one instance of contract research. The Permanent Commission of 1863 and the Naval Consulting Board of 1914 are illustrations of early advisory committees.

What have we said in reviewing these facets of Government support of scientific research? First, it is related to public need and second, it is governed through intimate connection with the people. Publicly dedicated officers of the Government administer the program—the more successful realizing the need to derive strength from their practicing colleagues and through such organizations of technical men as AIME.

SYMPOSIUM ON
GOVERNMENT-SPONSORED RESEARCH

Metallurgy Research Program . . . of the U. S. Army Office of Ordnance Research

Condensed from an article by Peter R. Kosting

THE Ordnance Corps was established in 1812; it has undertaken research and development ever since its inception and has not only stimulated, but also contributed, to our science and technology.

The Office of Ordnance Research, U. S. Army, was formally established in 1951 for the purpose of strengthening the basic research program. After a careful study of possible locations, the Office was placed within the *North Carolina Research Triangle*, made up of the University of North Carolina, North Carolina State College, and Duke University, on the campus of Duke University at Durham, N. C. OOR is a Class II Ordnance Establishment operated by the Ordnance Corps.

The mission of the Office of Ordnance Research includes the responsibility for basic research projects placed under contract at civilian research institutions. It is interested in the sciences having ordnance relevancy, but proposals pertaining to applied or technical research design and development are not within the mission of this office.

Proposals receive dual evaluation

Proposals for research projects are administered by the respective divisions of OOR and are evaluated for their scientific merit by referees selected by the National Research Council of the National Academy of Sciences. An overall rating is also supplied by the National Academy. The ordnance relevancy of each proposal in metallurgy is evaluated by staff members from three or more arsenals which have a responsibility in research and development in the applicable field. These two types of evaluations are taken into consideration at OOR by the Technical Review Panel which acts on the recommendations of the division regarding the sponsorship of each proposal.

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Exploratory research of new ideas

Funds are limited. Since there are ordnance agencies for sponsoring research to obtain fundamental information needed for a particular purpose, the tendency of the Office of Ordnance Research has been to facilitate exploratory research of new ideas of qualified individuals with moderate assistance rather than programmatic research by a team of investigators to supply information on a complex phenomenon of wide current interest.

The metallurgical program of the Office of Ordnance Research is principally in the area of physical metallurgy. Almost 70 pct of the current funds being dispersed are going into physical and mechanical metallurgy and physics of the solid state. The remaining 30 pct is divided between work on corrosion, ceramics, physical chemistry, and processing.

Liaison on the scientific plane is carried out at several of the ordnance laboratories, including Ballistic Research Laboratories, Frankford Arsenal, Picatinny Arsenal, Rock Island Arsenal, Springfield Armory, Watertown Arsenal, and the Redstone Arsenal. A total of 42 separate topics are currently being studied under the program, and these range from the very broad to the very narrow. However, in keeping with the goals of OOR contract program work, emphasis is on theoretical topics.

In addition to the proposals sponsored by the Metallurgical Div., there is roughly an equal number having metallurgical interest in overlapping areas of chemistry, engineering, and physics.

New basic ideas in the subfields of metallurgy are needed. The time is now here to consider the fundamentals upon which the engineer will build.

Some Aspects of Government-Sponsored Research in Metallurgy

Although the scientific findings of the United States Government's vast metallurgical research program are being reported constantly in scientific and professional journals, the symposium on "The Status of Government-Supported Basic Research Program In Metallurgy" at the 1957 AIME Annual Meeting, was the first time that an overall picture of this metallurgical program was presented publicly by those scientists who bear the responsibility for the administration and budgetary management of Government research contracts.

This paper presents the significant scientific and administrative aspects of the Government contract basic research program in metallurgy and ceramics.

by Julius J. Harwood

SINCE 1946, the U. S. Government, primarily through the activities of the Department of Defense and the Atomic Energy Commission, has engaged in a comprehensive contract research program for the support of basic research in the physical and engineering sciences. Beginning with the pioneering efforts of the Office of Naval Research, this program has grown tremendously, to the extent that numerous federal agencies have been established and millions of dollars are being expended annually for this sole purpose. Basic research in metallurgy, physics of metals, ceramics and related areas in chemistry, solid state physics, and applied mechanics occupy a significant share of this overall scientific effort. University, nonprofit, private, and industrial laboratories are participating in this contract program.

Government organizations for contract research program

This paper concerns itself only with the metallurgical and ceramics contract research programs of the following Government agencies:

Office of Naval Research (ONR), Department of the Navy,
Atomic Energy Commission (AEC),
Office of Scientific Research (OSR), Air Research and Development Command, U. S. Air Force,
Aeronautical Research Laboratory (ARL), Wright Air Development Center, U. S. Air Force,
Office of Ordnance Research (OOR), Department of the Army,
National Advisory Committee for Aeronautics (NACA), and
National Science Foundation (NSF).

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It must be emphasized, at the outset, that this report and those reports which follow, are only concerned with research being conducted under Government contracts and not with research underway in Government or quasi-government laboratories. The internal research programs of Department of Defense laboratories (e.g., Naval Research Laboratory), the National Laboratories of the Atomic Energy Commission, the NACA laboratories, and other Government laboratories (e.g., the National Bureau of Standards, the Bureau of Mines) have been excluded from consideration. In addition, since the discussion will be confined as closely as possible to basic research, the more applied Government contract research programs, such as supported by the Navy Bureaus of Aeronautics, Ships, and Ordnance, the Army Arsenals, and the Materials Laboratory of the Wright Air Development Center, have been excluded as well as any research activities conducted under various development and end-item production contracts. This phase of the Government research program is worthy, in its own right, of a separate presentation. Despite these omissions, the activities of the above-listed seven agencies probably comprise between 90 and 95 pct of the fundamental metallurgical and ceramics research being conducted under Government contract.

The major purpose of the Government contract program under discussion is to assist financially the performance of research. The prevailing philosophy holds that the Government does not and should not completely subsidize basic research. In a real sense the program is a partnership in which the Government and the research contractor are joint participants and contributors. Federal funds are provided for the assistance, acceleration, or expansion of research studies which originate with the research scientist in the university or research laboratory.

Table I. Distribution of Funds and Research Contracts by Agency as of January 1957

Agency	Funds		Contracts	
	In $	Pct of Total	Number	Pct of Total
ONR*	1,891,000	18.0	105	22.9
AEC	2,686,000	26.1	98	21.3
OSR	2,838,000	27.7	130	28.3
ARL	1,843,000	17.9	41	8.9
OOR	493,000	4.8	44	9.5
NACA	371,000	3.6	18	3.9
NSF	193,000	1.9	24	5.2
Total†	10,285,000	100	460	100

* Abbreviations of agencies listed on first page of text.
† In 1955 total funds amounted to $5,833,000.

Much of this research would be performed, regardless of Government support, but probably at a reduced rate or delayed in time.

It is worthwhile to note that the great bulk of Government contracts for basic research stems from unsolicited research proposals from the outside research scientist. Only occasionally does a basic research contract originate from a direct Government request for research in a specific area. The contacts between the investigator and the Government research administrator are those of scientific liaison. There is no deliberate attempt to direct the progress of research; rather our task is one of administration and coordination.

Motivation for Government support of basic research

One question which often arises, refers to the justification for such heavy support, by the Government, of basic research in the material sciences. Of the many reasons which can be offered, three probably stand out as the chief factors:

1) The important recognition after World War II that the wartime triumphs of applied science, e.g., radar, proximity fuses, and atomic energy, were the direct consequences of earlier decades of basic research (of other nations, to a considerable extent). It is now universally realized that continued and new technological successes depend upon a continuing flow of new scientific discoveries. Since universities are financially unable to support research programs of the necessary magnitude for this flow of new knowledge, the Federal Government had to assume this financial responsibility.

2) The recognition that the limitations of present-day materials represent one of the chief obstacles to the development of new and advanced military equipment and weapons and industrial processes. The underlying motivation for the support of basic research in metallurgy and ceramics is the firm belief that the more rational development of improved alloys and superior materials will be advanced and accelerated to a considerable degree by a more thorough understanding of the nature and behavior of the metallic state.

3) This Nation is now in the midst of a scientific revolution whose continued success depends upon the training of adequate numbers of scientists and engineers. Federal support of basic research in universities has been demonstrated to be an outstandingly productive method of educating and developing research scientists.

These three reasons, and others, justifying the Government's role in the support of basic research are, in reality, components of the important recognition that our Nation's security depends upon the maintenance of a healthy and vital basic research program.

Table II. Distribution of Total Funds by Field of Research

Field of Research	Total Funds, $	Pct of Total
Corrosion and Surface Reactions	805,000	7.9
Inorganic and Mineral Products	1,039,000	10.0
Physical Chemistry and Thermodynamics of Metal Preparation	480,000	4.7
Mechanical Metallurgy	1,361,000	13.2
Physical Metallurgy	1,609,000	15.7
Physics of Solids	3,505,000	34.0
High Temperature Materials	523,000	5.1
Metal Processing	122,000	1.2
Special Metals and Alloys	508,000	5.0
Titanium and Its Alloys	333,000	3.2
	10,285,000	100.0

Scope of Government contract research program in metallurgy and ceramics:

There exist few, if any, areas of research in metallurgy or ceramics in which Government contract support does not prevail. Indeed, in several significant areas, notably research on new metal and alloy systems, Government funding has been and is the main source of support.

Table I shows the distribution by agency of the current (as of January 1957) contract program for basic research in metallurgy and ceramics of the seven agencies under discussion. Of the $10 million involved, approximately 90 pct is administered by four agencies, ONR, AEC, OSR, and ARL. The four Department of Defense activities, ONR, OSR, ARL, and OOR, handle about 68 pct of the total funds. It should be made clear that this $10 million does not represent the total annual budget of these agencies for metallurgical research, but rather the actual total annual level of all contracts which are currently active, regardless of which fiscal year financing was accomplished.

Table III. Percentage Distribution of Individual Agency Budget by Research Field

Field of Research	ONR	AEC	OSR	ARL	OOR	NACA	NSF	Pct of Total Funding
Corrosion	12.8	4.5	11.9	2.4	9.5	1.6	6.2	7.9
Ceramics	18.7	12.7	6.8	6.4	7.7	—	—	10.0
Physical Chemistry and Thermodynamics	8.6	7.2	2.7	—	3.0	—	19.2	4.7
Mechanical Metallurgy	13.5	3.9	10.0	20.0	23.4	53.7	16.6	13.2
Physical Metallurgy	9.6	18.6	19.2	9.1	21.9	13.7	33.1	15.7
Physics of Solids	16.1	38.7	38.2	50.4	23.2	—	19.2	34.0
High Temperature Materials	9.5	—	5.4	4.2	—	31.0	—	5.1
Metal Processing	0.5	0.8	—	1.4	11.3	—	5.7	1.2
Special Alloys	1.1	13.6	2.2	3.2	—	—	—	5.0
Titanium Alloys	9.6	—	3.6	2.9	—	—	—	3.2
Total Pct	100	100	100	100	100	100	100	100

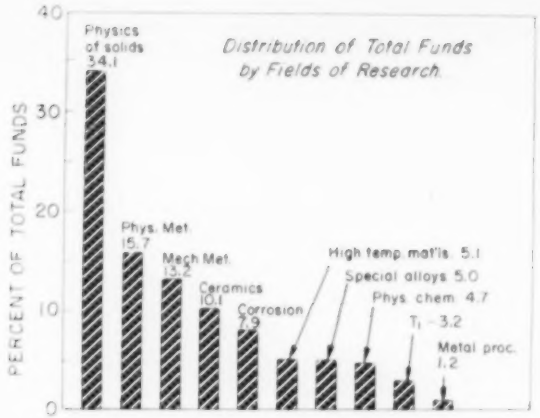

Fig. 1—The distribution of total funds by fields of research for the Government's contract research program in metallurgy and ceramics as of Jan. 1957.

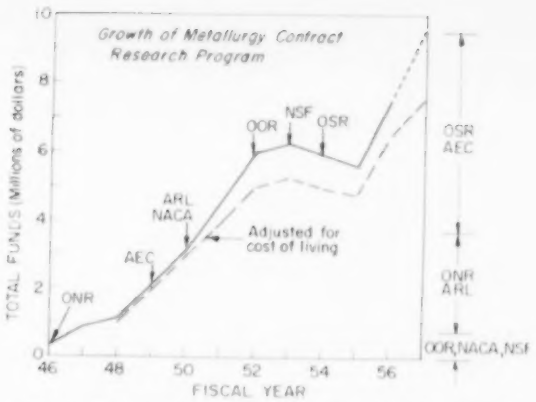

Fig. 2—The growth of the funds expended in the Government's contract research program in metallurgy and ceramics from 1946 to 1957. Arrows indicate the years in which the agencies began to operate with any substantial amount of funds. The dashed line represents these funds adjusted for the cost of living using the Bureau of Labor Statistics Index, base 1947.

The distribution of the currently active contract program by fields or research is shown in Table II and Fig. 1. Included in this program presentation are not only direct metallurgical research contracts, but also programs in solid state physics, electrochemistry, applied mechanics, etc., which are relevant to the categories. Table III shows the percentage distribution of the individual agency's budgets according to field of research.

It may be seen immediately that the largest concentrations of research effort lie in the areas of physics of solids, physical metallurgy, and mechanical metallurgy, representing 63 pct of the overall program. Interestingly enough, research support in physics of solids is, by far, the largest individual category, being greater than the combined effort in physical and mechanical metallurgy. This reflects, not only the basic nature of the program, but indicates as well the marked impact of recent advances in physics of solids, particularly imperfection theory, upon metallurgical research in general.

Surprisingly little effort along basic lines is indicated in the high temperature materials category. Partly, this is due to the inclusion of all high temperature deformation studies under mechanical metallurgy, and partly because the urgent immediate needs for improved high temperature materials has focussed much of the effort toward alloy development. This latter phase of effort is supported primarily under the more applied Government research programs.

In view of the growing importance of ceramics and inorganic materials from the viewpoints of high temperature structural usage and electronics applications, it is somewhat disappointing to note the relatively small emphasis in this area of research. A fair share of the research effort on semiconductors, ionic compounds, etc., is included under physics of solids, but probably the main factor contributing to the small effort in ceramics is the lack of good basic research proposals received for sponsorship consideration by Government agencies.

Corrosion and surface reactions is another area which would be supported to a greater extent if stimulating research ideas were forthcoming. The correlation of substructure and imperfections with reaction sites appears to be a fruitful area for future research. Another point is the relatively minor concentration of effort in the fields of special metals and alloys and titanium. As with high temperature alloys, most of the work in this field is supported under the more applied and development programs.

One interesting feature is that, despite a large increase in the size of the overall effort since 1955, the relative program emphasis and distribution has not significantly changed during the past two years.

Contract distribution to institutions

With over 450 research contracts in existence, it is of interest to examine the distribution according to research institution. Approximately 66 pct of the funds are expended in universities, representing about 78 pct of the number of research contracts. In the areas of physical metallurgy, mechanical metallurgy, and physics of solids over 85 pct of the effort is underway at universities. The distribution by individual agency is shown in Table IV. Two of the agencies, the Office of Ordnance Research and the National Science Foundation, deal exclusively with universities. The NACA has almost an equal distribution between universities and nonprofit research laboratories and maintains a policy of not supporting research in any profit-making organization. Some 77 universities are participating in the metallurgical contract research program and are geographically distributed throughout the country. There are, of course, heavy concentrations in certain universities which traditionally have been strong centers in metallurgy, but it is enouraging to note an increasing growth among universities which previously have not had active metallurgy departments. About seven nonprofit research laboratories and 27 industrial research laboratories are participating in the contract research program. A small percentage of the contract funds are allocated to Government laboratories, the chief one being the National Bureau of Standards.

In considering geographic distribution, it is of interest to note that the Office of Scientific Research is the only agency which has any sizeable contract research program involving European laboratories.

Growth features of Government sponsored basic research program

The increase in Government expenditures for the contract research program in metallurgy and ceramics has been spectacular. From about $1 million in

Table IV. University Participation in Metallurgy Contract Research Program

Agency	University Contract Funds	Pct of Total Funds	No. of University Contracts	Pct of Total Contracts
ONR	$1,276,000	69	79	75
AEC	1,676,000	70	72	74
OSR	2,170,000	77	101	78
ARL	622,000	37	22	56
OOR	493,000	100	44	100
NACA	196,000	53	11	61
NSF	192,000	100	44	100
Total	$6,626,000	66	373	78

Table V. Annual Agency Expenditure for Metallurgy and Ceramics Contract Program (in Millions of Dollars)

Fiscal Year	ONR	AEC	OSR	ARL	OOR	NACA	NSF	Totals
1946	0.41							0.41
1947	0.90							0.90
1948	1.08							1.08
1949	1.36	0.77						2.13
1950	1.11	1.30		0.48		0.25		3.14
1951	1.59	1.50		1.16	0.14	0.25		4.58
1952	1.72	1.98		1.33	0.68	0.25		5.96
1953	2.20	2.04		1.03	0.74	0.25	0.019	6.28
1954	1.12	2.14	0.85	0.96	0.52	0.25	0.078	5.92
1955	1.20	1.86	0.90	0.82	0.98	0.25	0.132	5.64
1956	1.53	2.17	2.10	1.36	0.50	0.25	0.117	8.03
1957 (Est.)	1.39	2.97	2.70	1.80	0.49	0.25	0.15	9.70
Totals	15.52	16.73	6.55	8.88	3.55	2.00	0.496	53.73

1947, which represents the first major operating year of ONR, the level has grown to slightly under $10 million in 1957. The increase has been rather steady and continuous, except for the period of 1953-1955, in which a slight decline occurred. From 1947 to 1955 most of the increase was due to the entry of additional agencies into this field of operations rather than to any major increase in the budgets of individual agencies. Since 1955 the increase in funds has taken a steep rise, from $5½ million to about $10 million, primarily due to the increased budgets of the AEC and the Air Force.

The funds expended by the individual agencies on research contracts for metallurgy and ceramics from 1946 to the present are tabulated in Table V. The overall growth pattern is plotted in Fig. 2 which indicates, as well, the years in which the various agencies began to operate with substantial funds. The peak in 1953 represents the full impact of the Korean military action and the consequent expansion of military research and development programs. The post-Korean decline between 1953 and 1955 was partially offset by the entry of the Office of Scientific Research into the research contract picture. Some $54 million has been expended over the period of 1946 to 1957 for the contract program for basic research in metallurgy, ceramics, and closely related scientific areas.

Costs: One of the important problems currently facing the Government science administrator, as well as all research laboratories, is the increasing cost of conducting research. It is becoming exceedingly difficult to stretch the research budget to accommodate rising costs and to maintain a well-rounded, vital program alert to the future needs of the nation. The dashed curve in Fig. 2 represents the annual expenditures as adjusted by the cost of living indices of the Bureau of Labor Statistics. The year 1947 was chosen as the base, since it represents the year in which the contract research program was in full operation. A weighted cost of living index covering primarily those items indigenous to research operation would have demonstrated the decreasing purchasing power of the research dollar even more strikingly. Based on the Bureau of Labor Statistics data, the 1957 research dollar retains only 80 pct of the purchasing power of the 1947 dollar.

Contract program in relation to total research budget: It is interesting to examine what fraction of the overall Federal research and development budget is allocated to the contract program for metallurgy and ceramics research. Data recently published by the National Science Foundation[1] allow some approximations to be made. In 1957 approximately $2200 million was allocated for applied research and development, whereas only $215 million was made available for basic research. Of the latter funds, about $139 million was for basic research in the physical sciences. Thus, the current level of about $10 million for the contract research program in metallurgy and ceramics represents about 4½ pct of the total basic research program.

As can be seen from Table VI the funds expended annually on Government contracts for basic research in metallurgy have occupied a fairly constant fraction, between 4½ to 5 pct, of the total annual basic research budget during the period of 1952-1957. A breakdown by agency for the current 1957 fiscal year basic research budget is shown in Table VII. While the right hand column in this Table is, at best, an approximation, it does indicate clearly the relatively higher emphasis by the Department of Defense Agencies in the fields of materials research, with a heavy concentration in metallurgy and related areas.

The overall Federal support in metallurgical research, including applied research contract programs and research performed in Government and Government-financed laboratories, is substantially greater than these figures.

Trends in research emphasis

In reviewing the scope of metallurgical research, which has been performed under Government sponsorship, certain trends may be noted.

For several years following the close of World War II, a heavy emphasis existed in the field of brittle fracture and ductile-brittle transition phenomena in steels. This was a natural consequence of the numerous ship-plate brittle fractures experienced by the merchant marine during World War II, as well as the need for alloys to withstand subzero operating conditions. A large amount of research was performed correlating transition temperatures with composition, microstructure, heat treatment, interstitials and impurities, state of stress etc. In the early 1950's research effort in this area lessened considerably, but it is interesting to note a recurrence of emphasis on the brittle fracture problem. This appears to be influenced by two main factors: 1) the increasing interest in such body centered cubic metals as molybdenum, chromium, columbium, vanadium, and tungsten, all of which exhibit brittle-ductile transition phenomena, and 2) the recent sophisticated approach to the problem of fracture, based upon dislocation theory.

Another problem which received a heavy concen-

Table VI. Relationship of Metallurgy Research Contract Program to Total Federal Basic Research Expenditures

Fiscal Year	Total Basic Research Funds (in Millions of Dollars)*	Metallurgy and Ceramics Contract Research Funds (in Millions of Dollars)	Pct of Basic Research Funds for Metallurgical Contract Program
1952	117	5.96	5.0
1953	113	6.28	5.5
1954	116	5.92	5.1
1955	130	5.64	4.3
1956	162	8.03	4.9
1957	215	9.7 (approx)	4.6 (approx)

* National Science Foundation data

Table VII. Estimated Expenditures for Basic Research by Agency for Fiscal Year 1957 (in Millions of Dollars)

Agency	Total Expenditure-FY57*	Pct Expended in Metallurgy Research Contract Program
Army	4.15	~12
Navy	8.03	~20
Air Force	15.6	~29
Dept of Defense	27.8	~24
AEC	56.7	~5.5
NACA	14.6	~2
NSF	42.6	~0.5

* National Science Foundation data, fiscal year 1957

tration of research effort during the early years of Government research sponsorship was that of high temperature materials. Research in this area was motivated by the growing development in the field of gas turbines. A great deal of research was initiated on creep and the study of the fundamental factors responsible for high temperature strength and resistance to deformation. Practically all current research under Government contract on creep and high temperature deformation is utilizing the concepts of dislocation and point defect theories, with considerable attention being directed to void formation and vacancy condensation effects.

Two other approaches, of a somewhat less basic nature, also received emphasis in the fields of high temperature materials: the development of molybdenum base and chromium base alloys and the development of cermets (metal-ceramic combinations). The successful development of molybdenum alloys with outstanding high temperature strength properties has focussed increased attention on the other refractory metals, e.g., columbium, tungsten, tantalum. Some recent success in developing ductile chromium-base alloys will stimulate new approaches to the problem of brittleness in these high-melting, body-centered-cubic metals. The development of cermets has also, to some extent, bogged down in the brittleness problem which has led to the current emphasis in research on the study of the ductile matrix-hard compound interaction, in terms of fracture initiation and propagation.

The single outstanding trend which has become paramount during the past few years is the tremendous impact exerted by solid state physics upon metallurgical research. There is little research underway on deformation, fracture, or transformations which is not motivated or influenced by the concepts of dislocation and imperfection theory. It has been encouraging to observe these concepts exert an influence upon recent research in the fields of corrosion and ceramics.

Impact on literature, education, and equipment

The scientific findings of the contract research program are being reported continuously and extensively in the metallurgical literature. About 775 papers were published in engineering journals as a result of metallurgical and ceramic research studies supported by the Office of Naval Research during its first ten years of operation. It may be anticipated that several hundred scientific papers will appear annually as an outgrowth of the present overall level of Government support of metallurgical research.

It would be meaningless, if not impossible, to attempt the separation of the scientific achievements of Government supported research from the overall advances in the science of metals and ceramics. The important point is that there can be no question that Government financial support has provided a tremendous assist and stimulus to the progress which has been made during the past ten years in all phases of metallurgical and ceramics research.

The impact on education: One of the features of the contract research program in which all Government agencies take considerable pride, regardless of whether it is a primary or secondary consequence of their particular mission, is the education impact of Government sponsored research. Using data compiled by the Office of Naval Research to illustrate this point, some 180 M.S. degrees and 190 Ph.D. (or D.Sc.) degrees were granted as a direct result of metallurgical and related research conducted with ONR financial support. Extrapolating the data published recently by Bever[1] on the supply of metallurgists with graduate training, it appears that some 40 pct of all doctorate degrees (approximately 475) granted in metallurgy during the period of 1948-1956 directly benefited from ONR research contracts. The funds now being allocated annually for university research contracts by the seven agencies under consideration represent some 50 pct of the total funds expended by ONR during the above mentioned period of time. It seems quite probable, therefore, that Government financial support of research, in one form or another contributes to about 50 pct or more of the metallurgy doctorates granted each year.

Research equipment: Another byproduct of the contract program has been the increase in metallurgical research equipment and facilities in university laboratories. The determination of what portion of the contract research budget should be allocated for the purchase by the contractor of expendable and capital equipment varies from agency to agency. This determination always is complicated by the realization that equipment dollars are available only at the sacrifice of direct research dollars. In addition, under most Government contracts, the Government retains title to capital equipment purchased under the contract, which may lead to complex situations upon the expiration of a research contract. However, under the NSF grant program and the AEC contract program, equipment title often resides with the con-

tractor. More recently the NSF has paid special recognition to the research equipment needs of universities and has allocated special funds for this purpose.

Problems in research contract administration

The scientific research contract is a relatively new concept in government operation. The objective of *buying* research or research reports and not brooms or hardware has necessitated an entirely new contractual approach on the part of Government agencies sponsoring basic research. This was recognized early by ONR, which established its own internal contracts division to formulate contracting procedures for maximum mutual benefit to the Government and universities, i.e. allowing the university its proper and traditional academic freedom within the framework of Federal contract regulations. The system, which was devised, has been eminently successful and has served as a model for some of the other agencies undertaking similar operations.

Although some standard Government contract procedure, such as competitive bidding, were discarded as impractical for basic research contracts, new types of administrative problems have arisen as inherent features of the contract program involving such a large Government-university interaction. The consequences of the influence of Federal funds on universities are being examined constantly and many of the problems are being solved jointly by university and Government officials.

Since the question of duplication always arises, it can be stated categorically that coordination of the Government contract research program in metallurgy and ceramics is most effective. Numerous official Government advisory and coordinating committees are active along these lines, but of greater importance are the coordination and information exchange activities between the science administrators on a working level. There exists an informal Inter-Agency Metallurgy Research group which meets periodically to discuss the status of their programs and to resolve common issues. In addition, a good working procedure has been established whereby each agency knows reasonably promptly of the proposals being considered and the contract action of the others. Duplication is the least of the problems.

Summary: An effective system has been evolved for the administration of Government basic research contracts which includes the following points:

1) The university investigator is the focal figure in the research program; he is free to select his own research problem and to conduct the investigation to his own liking;

2) The contract form is kept simple, the scope of the work is defined in broad terms and a good deal of discretion is allowed in the expenditure of allocated funds;

3) The requirements for reports and administrative control are kept to a minimum; Government liaison is primarily of a scientific nature; and

4) The performance of research is the contract objective, and specific goals, time schedules, or program plans are not narrowly confined.

Future of Government sponsored research

The recognition of the potent force of science in modern civilization and its indispensability to national security assures the continued support of basic research by the Federal Government. The important role of materials in this age of technological developments assures equally the allocation of a proper share of such support to the fields of metallurgy and ceramics, although it has been claimed by many that materials research support has not kept pace with its growing importance to Government development programs, particularly those of the Armed Services. In advanced military weapons and equipment, the requirements for materials are increasing at a faster rate than knowledge about their properties and behavior, and the importance of basic research in the materials sciences needs further emphasis.

Extrapolating certain trends which are being manifested, some of the areas for future research in which current interest exists are:

1) Development of new and more sensitive metallurgical tools and techniques;

2) Behavior of metals at *super* high temperatures and extremely low temperatures;

3) Deformation behavior of intermetallic compounds, ceramics, and related inorganic solids;

4) Influence of high pressures on solid-state reactions;

5) Refractory metal and alloy systems;

6) Influence of environment on deformation and fracture behavior;

7) Dispersion-hardening and *fine-particle* strengthening;

8) High-temperature electronic materials; and

9) Micro-mechanism of initiation of fatigue.

The university scientist will remain the key individual in the Government Contract Research Program. It is his leadership which is needed in the conception of fresh and original ideas and in the exploration of new, fruitful fields of metallurgical research. His assistance is needed, also, in the formulation of the research problems basic to the long range improvement of materials and in the development of independent approaches to these problems. The university scientists should beware, therefore, of orienting his research thinking and experimental studies along *popular* lines because of the belief that these will most readily receive Government financial support. He should not be reluctant to submit imaginative suggestions for research support. Quite frankly, we urge that no attempt be made, in the submission of research proposals, to *second-guess* Government research administrators. The existence of different agencies with different motivations, different programs and interests, and different operating mechanisms will always provide a source of funds for worthwhile research ideas.

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SYMPOSIUM ON
GOVERNMENT-SPONSORED RESEARCH

Metallurgy Research Program . . . of the Air Force Office of Scientific Research

by Charles F. Yost

THE Air Force Office of Scientific Research (AFOSR) is charged with the mission of "fundamental, theoretical or experimental investigation to increase man's knowledge and understanding of the natural world and to recognize the implications of new scientific knowledge and new weapons concepts."

In 1951 the Department of the Air Force established the Air Research and Development Command (ARDC) as a major command. The Air Force Office of Scientific Research was activated as a field organization of the ARDC in August, 1955, as one of 12 centers devoted to various aspects of research development. AFOSR is the center that has prime responsibility in the field of original investigation.

The Air Force Office of Scientific Research has a triune job to do. It must plan, formulate, and manage the exploratory research program for the Air Force that will insure maximum strength and efficient use of the strategic scientific potential of the U. S. and its allies in support of air technology. Second, it must establish and maintain contact with the scientific community of the *free world* in such a manner that the existence of new research results will be immediately known, and their implications recognized for application to new strategic concepts for the continued improvement of existing weapons systems. And finally, it must maintain cognizance of the major research and development activities supported by governmental and private agencies, to maximize productivity of their research activities and their applicability to the special needs of the Air Force.

In standard military practice a *requirement* is set up—say for a vehicle which can fly *X* knots at *Y* altitude carrying *Z* lb. As this requirement is broken down into the necessary bits and pieces, it is discovered that existing materials and techniques are not adequate to meet this requirement, and that it is necessary to discover something better. This search—for an improvement in answer to a specific question or need—is called *supporting research*. Its application can be visualized up to the entire continuum of development, culminating in production military hardware.

Exploratory research is something else again. It provides answers to which there have been no questions. Exploratory research is research undertaken to add to the sum total of human knowledge in areas of interest to the Air Force. Exploratory research provides *capabilities*—capabilities for developing new concepts of weapons systems that may revolutionize the art and science of aerial warfare. These capabilities will probably have to be carried through the initial exploratory stages of development before their possible military applications can be visualized.

Supporting research, as herein defined, has a relatively high probability of success, and a relatively low pay-off. Exploratory research has a relatively low probability of success, and a very high payoff if successful. Supporting research might be likened to a bond, exploratory research to a common stock; a sound portfolio contains both.

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Solid state sciences program

The ultimate aims of the exploratory research program in the solid state sciences are 1) to make better use of desirable physical properties of solids for Air Force use, and 2) to discover new phenomena that might lead to novel applications.

Particular emphasis is given to studies of the properties of imperfections in solids, how to control them, and their influence on the physical properties of solids. Metals, semiconductors, and insulators are considered, and the kinds of imperfections under study are phonons, electrons and holes, excitons, vacant lattice sites and interstitial atoms, impurity atoms, and dislocations. Investigations of the nature of these imperfections and how they affect the physical properties are not confined to the interior of the solid; the role played by imperfections in surface phenomena, such as radiation damage and corrosion, is also important. In general, the study of imperfections might be categorized under one of two headings: 1) fundamental research in solids which has as its primary aim the clarification of existing knowledge, and 2) fundamental research which has as its primary aim the exploration of new phenomena.

The research program itself has the overall aim of synthesizing—what may appear to be—unrelated research efforts in order to make a general coordinated picture of the nature of solids, such as one does in fitting together the pieces of a puzzle. Out of the fundamental investigations of these materials it is hoped will come better use of existing materials or new materials to meet the many challenges confronting us in the air age.

SYMPOSIUM ON
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Metallurgy Research Program . . . of the National Science Foundation

by E. E. Litkenhous and Gene M. Nordby

CONGRESS took an unprecedented step in 1950 when it created the National Science Foundation. For the first time in our history an independent agency was established to encourage and stimulate basic research in engineering, physical, and other sciences. One phase of this stimulation consisted of granting funds to carry on various research activities. Two divisions of the Foundation deal almost entirely with the promotion of research and increasing the basic research potential of the country. The activities in the field of metallurgy are administered in the Program for Engineering Sciences.

The research activities of the Foundation are distinguished by the fact that the NSF has no specified objectives dictated by military considerations or commercial use. The only real objective is aimed at filling the fund of knowledge through excellent basic research and making the same available for later use. The Foundation does not ignore the secondary accomplishments of the research program, which consist of: 1) the education and training of students, primarily at the graduate level; 2) the development of small departments in the colleges and universities; and 3) the development and education of the investigators themselves.

The research grant

The core of activity in the Engineering Sciences Program revolves around the research proposal. The proposal is the device by which the scientist initiates a research project by proposing a specific area of study. It is reviewed by engineering specialists by what is known as the *referee* system. Reviews are obtained from at least one member of the Advisory Panel for Engineering Sciences of the Foundation and, in addition, from many engineering specialists in the particular field of interest in which the project falls. Their rating is based on the applicant, institution, and subject of the particular proposal. Over 600 reviewers in the engineering sciences field have volunteered their services in the past five years in evaluating proposals for the National Science Foundation. After the proposal has received satisfactory evaluation by reviewers, it is passed on to the National Science Foundation Board for approval, and then awarded a grant.

The grants themselves are simple and flexible. They are, in a sense, gifts, and consequently there is a minimum of reports and detailed information requested from the grantee. The Foundation does request a bi-annual financial statement and six copies of any publications that result from the grant. Although a final detailed report is not requested, the principal investigator is encouraged to publish in existing engineering journals. There is typically no *property accountability* with a Foundation grant as there is in some Government contracts. As a result, the equipment purchased through the grant generally becomes the property of the institution.

Changes in the current rate at which research progress is being carried out on a specific project or changes in the directions of the research lie in the hands of the principal investigator working within the framework of the institution. Changes in the direction of the research and deviation from the original proposal are encouraged when the principal investigator feels it is in the best interests of science. There are no rigid deadlines, nor is there any pressure to produce desired results or to solve a particular problem. The grants are so designed to make it simple to do research, to enhance the teaching abilities of the investigator, as well as to fit in smoothly with academic life.

Grants for major facilities

The Engineering Sciences Program is now studying the major facility needs for basic research in engineering schools throughout the U. S. Preliminary estimates show this need to be extensive—in the amount of several hundred million dollars. The Foundation is also considering the extent of Governmental responsibility in furnishing these needs. The American Society of Engineering Education is making a more detailed study of these needs through an NSF grant. This study will be completed next year.

Conferences and foreign travel

Other activities which are included in the Engineering Science Program are support of conferences and grants for attendance at international meetings.

Engineers recognize the value of small conferences dealing with subjects of limited scope where discussions are extensive. In this case the Foundation might finance all or part of the expenses as a sponsor or co-sponsor with a scientific society. A conference is initiated by a proposal from a prospective sponsor much the same as a research proposal.

Metallurgical activities

A total of 21 projects are supported at the present for a total of approximately $400,000. There is, however, no allotment given specifically to the field of metallurgy. In awarding grants, preference is given to those current proposals that have the best rating, and as a consequence of this procedure, some subject fields receive more grants than others. Inasmuch as metallurgy has many sources of support at the present, the Foundation probably receives proportionately fewer of these proposals as compared with those in other fields.

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SYMPOSIUM ON
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Metallurgy Research Program . . . of the Office of Naval Research

by Julius J. Harwood

THE philosophy, mode of operation, and administrative management of the ONR contract research program in metallurgy and ceramics have been adequately covered in the previous discussion of the overall Government contract program. However, there are certain specific features of the ONR operation which warrant brief consideration.

Since its inception, the Office of Naval Research has maintained a strong emphasis in the fields of deformation and fracture, transformation kinetics and mechanisms, physics of metals, high temperature materials, corrosion, and ceramics. It is anticipated that in the near future continuing emphasis will be placed in these same research areas, with increasing attention to high and low temperature metallurgy (transformations, deformation, and fracture), techniques of preparation and properties of super high purity metals, and ceramics research (particularly deformation behavior).

Titanium program

In 1952 a research program was initiated on the physical chemistry of the extractive metallurgy of titanium. The initial objectives of this program have been accomplished, and a book compiling the physical properties and thermodynamic data on titanium compounds and related materials is in the midst of publication by the Government Printing Office.

The needs for improved high-strength high-temperature titanium alloys led to the establishment of a special research program in 1955 on the physical metallurgy of titanium alloys. Research in this area was concentrated on the influence of retained β on the properties and on the kinetics of β transformations. Titanium metallurgy, in the future, will be included as a component of the general physical metallurgy program of ONR.

Long-range contracts

The basic contract research program has been insulated from sharp budgetary variations. It has always been a deliberate policy on the part of ONR to protect the stability of its basic research program from the inherent variations in supplemental Naval funds. The fact that the number of research contracts has remained independent of these fluctuations, and indeed has shown a steady increase, demonstrates the success of this policy.

In 1952, a significant fraction of the metallurgy contract research program was placed on a truly long-range basis, i.e, a sizeable number of research contracts were negotiated for periods of duration ranging from two to four years. These advanced contracts provided obvious benefits to universities with respect to financial and personnel stability and scientific flexibility.

This long-range program has been one of the major factors enabling the insulation or *cushioning* of the basic research program from external budgetary fluctuations. As of January 1957, 20 research contracts, representing about 25 pct of the number of contracts and 33 pct of the annual budget of the ONR contract research program in metallurgy and ceramics, were on a long-range basis.

ONR coordination function

There is one operational feature of the ONR which is not as well known as its contract research program, and that is its coordination function. Not only is the contract basic research program integrated within the overall Navy research and development effort, but also ONR bears the responsibility for the coordination of all Naval research and development. Coordination, we believe, is not merely the exchange or dissemination of information, but, more fundamentally, it is the planned objective of obtaining the most value for the Navy's research and development dollar. Thus, a number of intra-Navy coordinating groups have been established for the purpose of formulating integrated Navy programs, extending from basic research through the stage of application engineering. The ONR contract basic research program does not operate within a vacuum, but it is responsive to the growing materials needs and requirements of the Navy. Lest this provide an erroneous impression, there should be no inference that the basic research program is tied directly to end-item development. There exists ample room for free and imaginative fundamental research. Our objective is to ensure that Naval applied research and development programs are adequately supported by the necessary basic research, so that new ideas, principles, and theory can be fed, when practicable, into alloy and materials development programs. The problem of translation of research findings into engineering language is one which will require more attention in the future.

Another aspect of the ONR coordination effort stems from the scientific liaison activities of our London Branch Office. As is well known, ONR London has endeavored to facilitate the exchange of scientific information between European scientists and their counterparts in the U. S.

The Office of Naval Research has just completed a decade of activity in the sponsorship of research contracts. The participation and cooperation of scientists in universities, and private and industrial research laboratories in the program has been extremely gratifying. We look forward with anticipation and confidence during the next ten years to the same productive partnership between research scientists and the Navy.

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SYMPOSIUM ON
GOVERNMENT-SPONSORED RESEARCH

Metallurgy Research Program . . . of the Atomic Energy Commission

by Edward Epremian

THE Metallurgy and Materials Branch of the Research Div. of the Atomic Energy Commission is concerned with the fields of metallurgy, solid state physics, and ceramics. The program places particular emphasis on the basic aspects of these fields, because applied and development work is supported by other AEC divisions, such as Reactor Development, Military Applications, Production, and Raw Materials.

The research program is conducted at the AEC National Laboratories, at universities, and at certain industrial and research institutions. The total program during the present fiscal year is about $7 million, approximately 60 pct of which is at the National Laboratories. The remaining 40 pct is the portion included in the analysis by Harwood on p. 666. Research at the National Laboratories is similar in nature and approach to university research, and almost all of it is unclassified, but for the purpose of this paper, remarks are confined to areas of research, objectives, and some policies pertaining to university research.

The research might be divided into two general categories: first, investigations on materials of current or potential use in the atomic energy program, and, second, studies designed to seek and understand new phenomena. The AEC would like to have both conducted with the spirit and techniques of fundamental research. Included in the first category are studies on materials of interest in nuclear reactors, such as uranium, thorium, zirconium, beryllium, columbium, graphite, various ceramics, and the rare earths. Here the emphasis is on the specific material, and the objective is to understand and control its properties and behavior.

Fundamental studies of properties of solids

The second category, which involves the universities to a greater extent, is devoted to fundamental studies designed to increase the understanding of the nature and properties of solids. In this case, investigators have a free hand to work with those materials which are experimentally convenient and theoretically interesting, since the aim is to seek and understand new phenomena.

The AEC feels that it can be most effective by supporting certain areas which are relevant to the atomic energy program. With reference to Harwood's Table III, p. 666, the AEC places great emphasis on *Physical Metallurgy* and *Physics of Solids*. Little emphasis is placed on *Mechanical Metallurgy* because most materials applications in atomic energy involve only moderate stresses under static conditions. A great deal of attention is devoted to *Special Metals*, *Physical Chemistry*, and *Thermodynamics of Metal Preparation*. Item one, *Corrosion and Surface Reactions*, is probably the most neglected field in the whole metallurgical research program, particularly in relation to its importance. We have been trying (without particular success) to strengthen fundamental university research in this area, but the fact of the matter is that during the past year or two we have received few meritorious proposals on this subject.

Areas of special emphasis

Quite apart from the two general categories used in describing the program or the ten items used to analyze the activities of the various agencies, there are certain areas which are being given increased emphasis:

1) First there is the research in high temperature metallurgy. Every effort is being made to increase the activity on such subjects as transport phenomena, thermodynamics of compounds, solubilities and rates of solution of solid metals in liquid metals, nucleation and growth phenomena, and gas-metal solubilities and reactions.

2) The metal columbium has a number of attractive features as a reactor material. The AEC has built up a research program on this metal starting with new extractive processes and extending to physical metallurgy and properties.

3) Liquid metals play an important part in the atomic energy program either as a coolant or as a fuel bearing medium, such as in the liquid metal fuel reactor. The AEC has supported work on liquid metals for years, but recently has developed a more basic program on the liquid metallic state; this effort includes a number of university studies on thermodynamics, specific heats, diffusion, attenuation of ultrasonics, and X-ray and neutron diffraction.

4) The present program on the effects of irradiation on materials ranges from rather practical work, involving experiments designed to show how the properties of materials change upon neutron bombardment, to more fundamental investigations, where irradiation is used as a tool to introduce defects in a lattice for detailed study. In between these two, there is a middle ground which includes the effects of irradiation on physical metallurgical re-

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actions; for example, how does irradiation affect the kinetics of precipitation from solid solution, or the kinetics of phase transformations, recrystallization, or diffusion.

5) In the past, most of the work on materials of potential use as fuel elements in nuclear reactors has been devoted to uranium and its alloys. The AEC has now become convinced that it would be desirable to invest funds toward an improved understanding of the various compounds and intermetallics of uranium.

6) Progress in many research programs is being delayed because of the difficulty in obtaining materials of sufficiently high purity and single crystal samples. The AEC surveyed some of its research contractors and received an overwhelming expression of need for very high purity metals, oxides, metallic halides, and semiconductors, including single crystals. Various opportunities for developing sources of supply to meet this demand are now being considered.

7) Lastly, the AEC is now laying plans to broaden the base of its solid state physics effort, which in the past has been aimed primarily at an understanding of irradiation effects.

Policies for support of research at universities

The AEC's approach is based on the attitude that it is assisting the university in doing the research the university wishes to do—provided, of course, there is a common interest. In keeping with this attitude, about 90 pct of the projects supported at the universities are the result of unsolicited proposals.

The Commission's policy of financial support is designed to ensure that the university contractor has a genuine interest in the research and is not merely undertaking a task because support is available for it. There is a joint participation scheme whereby the AEC and the university share the cost of performing the work. Not only does this policy enable the AEC to assist more research people with a given amount of funds, but it tends to assure that the academic institution has a strong interest in the research. If the university contribution is sufficient, the contract is written to specify that title to the equipment purchased under the contract is vested in the university.

The support of research by a Government agency is based on the program concept whereby a number of investigators are supported in the study of related topics on some given subject such that the whole is greater than the sum of the individual parts. This being the case, the responsibility of the sponsor begins rather than ends with the provision of funds to the contractor; the agency must perform a coordinating function and encourage the necessary interaction between the research people. This can be achieved by facilitating the exchange of reports and visits by the scientists, the organization of informal meetings and various symposia and seminars, and other means. We believe that this function is an important one in carrying out an effective program.

The Commission's feeling of responsibility extends beyond those whom it supports to a real concern and interest in the strength of basic research on materials in the U. S.

A complete description of AEC supported projects is available in TID-4005 (Pt. 1, 4th Ed.), available from the Office of Technical Services, Dept. of Commerce, Washington 25, D. C. at a cost of sixty-five cents.

SYMPOSIUM ON
GOVERNMENT-SPONSORED RESEARCH

Metallurgy Research Program . . . of the Aeronautical Research Laboratory

by James W. Poynter

AT Aeronautical Research Laboratory, Wright Air Development Center, the term *metallurgical research* includes research on ceramics, cermets, and magnetic and electronic materials, in addition to research generally designated by that term. The research program is conducted both by internal effort and by external contracts, but this paper is concerned only with the latter.

Programs or projects are prepared to outline plans for research in various scientific fields where the attainment of additional knowledge will be of value to the Air Force. The research is separated into somewhat specialized areas—called tasks—and the work to be done in each of these areas over a period of several years is planned as definitely as possible. This planning is based on the relative importance of the various future Air Force requirements, a knowledge of the scientific work now being done in the area, an awareness of the availability of research capabilities in the field, and the ability of our Laboratory to assist in and to guide the expenditure of funds.

JAMES W. POYNTER is Assistant Chief, Metallurgical Research Branch, Aeronautical Research Laboratory, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio.

An invitation-to-bid

The invitation-to-bid is a formal request which the Procurement Div. sends to known workers in the specialized field involved, asking them to submit proposals for conducting research investigations on the stated subject. The basis for the preparation of an invitation-to-bid is an individual item of research or a single problem. They are usually written in rather general terms which merely define the problem or subject on which research is desired. Consequently, each investigator has full freedom to select the exact problem he wishes to study and to show his initiative and resourcefulness in the ap-

proach and experimental techniques which he chooses to use.

All the bids submitted by the specified date are carefully evaluated for scientific value with no consideration of the amount of the bid. The factors considered in this evaluation include the experience and reputation of the principal investigator, the qualifications of those who will be associated with him in the work, the comprehension of the problem, the originality and the soundness of the proposed approach, the adequacy of his laboratory facilities, differentiation from related work being done by other investigators, and the likelihood of successful accomplishment. The best proposal from the scientific viewpoint is selected and the contract negotiated. If the amount bid should be in excess of the funds allocated, it is necessary to arrange for the work to be done at a lower rate of effort to conform to the available money.

Unsolicited proposals

Many investigators ask about our attitude toward unsolicited proposals for research work. The reply is simple. The ARL welcomes them and encourages their submission. An answer to any unsolicited proposal is given promptly. Even though all of them cannot be accepted, they afford a very good way of learning of the areas of specialization and qualifications of individuals and groups interested in various kinds of metallurgical research. These individuals can then be invited to bid on any future research when the subject might be of interest to them.

Only a few of these unsolicited proposals can be awarded contracts on a *sole source* basis, because of existing regulations. Sole source means awarding a contract for work without competitive bidding. In general, procurement policies and regulations require competitive bidding as a basis for awarding a contract whether it is for research work or for procurements of equipment or supplies. Consequently, unsolicited proposals received for research using conventional approaches and laboratory procedures must usually be handled on a competitive bidding basis. It is only when the unsolicited proposal involves a unique approach to a problem, when the investigator is uniquely qualified by experience and ability, or when the proposal covers work on a new and novel problem, that procurement on a sole source basis may be permissible.

In some instances, an unsolicited proposal is designated as *confidential* by its originator. Before a proposal so designated can be evaluated, the submitter must sign a policy agreement. In essence, this states that due care will be exercised in handling and evaluating the proposal but that no liability is assumed from confidential disclosure and no obligation is incurred to accept the proposal. The proposal is then evaluated in the usual way, with due regard to its confidential nature. An accepted proposal is the basis for a sole source contract.

Research contracts

Ordinarily the rate of a single effort is between $25,000 and $50,000 per year. Obviously there are exceptions which may be either significantly above or below this range, depending on special considerations. These contracts are placed with universities, nonprofit institutions, industrial laboratories—both in the USA and abroad—and with other Government laboratories. Contracts are almost always written to cover one year's work; however, the ARL program is so planned that the contract will be renewed from year to year so that the investigator can do a reasonably complete piece of research on his problem. This generally requires three to five years, although here again there are exceptions.

In common with the other Government agencies, the ARL fiscal year begins the first of July. Many contracts are written or renewed during the next several months. As a result, the funds available for new work decrease during the latter part of the fiscal year and it is occasionally necessary, with the full concurrence of the submitter, to hold accepted proposals for funding during the next year.

On all unclassified work—and practically all of our sponsored research falls into this category—the investigator is strongly encouraged to publish his results as a research paper. The results of sponsored research are also published as Wright Aid Development Center technical reports.

Selecting research subjects

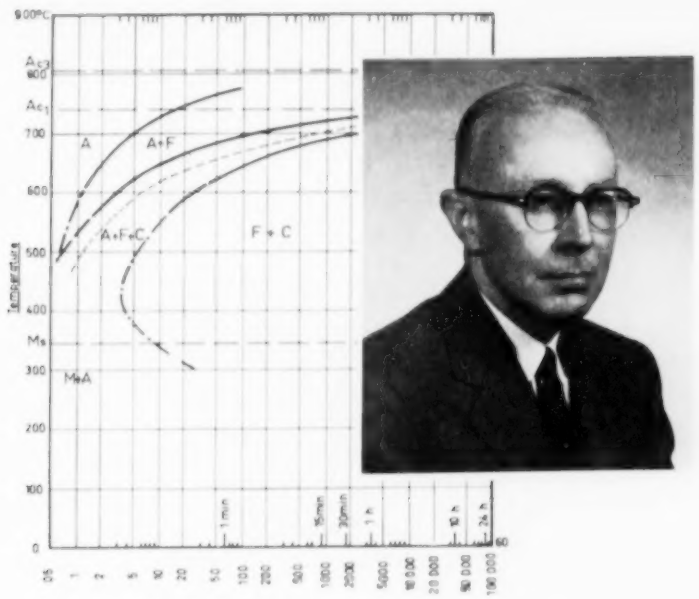
In selecting research subjects we favor, other factors being comparable, work in the newer, off-the-beaten-path fields which seem to promise the possibility of significant accomplishment rather than additional work in a field in which much has been done previously.

A field of major importance is that of research on the internal structure and properties of matter. This includes an area of work on the interactions between ions, atoms, and molecules in metals, alloys, and ceramics, and on the causes and effects of various kinds of imperfections in the lattice. The aim of this work is an adequate theory of alloying.

A second area of research in this field is that on the effects of various environmental conditions on the internal structures of solids. These environmental conditions include radiation, very rapid heating and/or cooling rates, applied steady or changing stresses, and pressure. Included here would be research on the possibility of producing a metastable equilibrium in some system that would have unusual characteristics. This area is of increasing importance. Another area deals with the mechanisms of deformation and deformation behavior of solids. This encompasses work on single and polycrystals of both metallic and ceramic materials. The ARL is quite interested in studies on the factors controlling the ductile behavior of ceramics and would welcome proposals for work on some aspect of this.

An area of much current interest is the work loosely characterized as *electronic and magnetic materials*. The expanding program in this field and a few rather large contracts are the principal causes of the very high figure shown in Harwood's category *Physics of Solids*, Table III, p. 666. It is anticipated that interest in this kind of research will increase, since adequate control and operation of some of the newer weapon system concepts will ultimately depend on increased knowledge in this field.

The area of most intense interest at present is more knowledge of the effects of radiation on semiconductors, magnetic materials, intermetallic compounds, conductive materials, etc. Our present work in this area includes studies of the magnetic characteristics of fine powders, the conductivity mechanism in thin metallic films, the conductivity of ferrites, radiation effects on semiconductors and intermetallic compounds, and studies of certain intermetallic compounds to determine if some of their characteristics conform to theoretical predictions.



Some Observations on Ferrite-Carbide Aggregates in Alloy Steels

by E. S. Davenport

IT is indeed an honor and a responsibility to have been selected to present the thirty-fourth in this series of Henry Marion Howe lectures, established to perpetuate the memory of a great teacher and one of America's outstanding scientists. Previous Howe lecturers have established high standards for this annual AIME event. It has been my good fortune to have enjoyed close association with five of these former lecturers; namely, Bain, Grossmann, Johnston, Sosman, and Vilella, all of whom have been prominently identified with the research activities of the organization with which I am connected.

Some years ago I had an opportunity to examine a letter written by Professor Howe in 1904. This document was particularly interesting to me since I never had the privilege of personal acquaintance with Professor Howe and do not recall even having seen him during his long and active career. In view of the fact that the letter dealt, to some extent, with matters related to the subject of today's lecture, I would like to quote briefly from it.

The letter is datelined, "Bad Kissingen, June 11, 1904." The salutation reads, "Dear Bradley," which suggests that it was probably addressed to Bradley Stoughton, who, I believe, was working with Howe at Columbia University at that time. The letter reads, in part, as follows:

> "*Austenite and Martensite.* I have not examined what Osmond says in his new book. His former remarks about austenite I found very confusing, indeed unintelligible. I think we can reconcile matters well enough for the present by assuming that martensite is a transition step between austenite at one end and ferrite and cementite at the other. Above critical range for steel of 0 to 1.80 carbon, austenite is normal state; below Ar_1, ferrite and cementite are normal."

The letter then continues with a discussion of Osmond's ideas on metallographic nomenclature, particularly his use of the terms martensite, troostite, and sorbite, including the following pointed comment:

> "For common purposes it seems to me unwise to drag them in, and much simpler to confine ourselves to the end stages
>
> $$\left(\frac{\text{Austenite}}{\text{Ferrite plus Cementite}}\right).$$
>
> Osmond does not really know his own mind—or does not clarify his ideas to others—as to nomenclature."

Thus we see that, as far back as 1904, the transformation of austenite, and the products of that

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TP 4485C. Manuscript, Feb. 20, 1957. New Orleans Meeting, February 1957.

The Transactions papers appearing in JOURNAL OF METALS *during 1957 will subsequently appear in AIME Transactions Volume* 209, *and may be permanently referenced to that volume.*

Water quench—Rc 64

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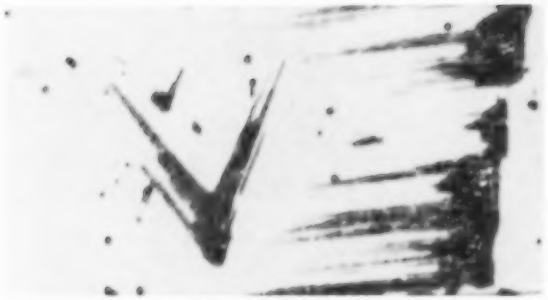

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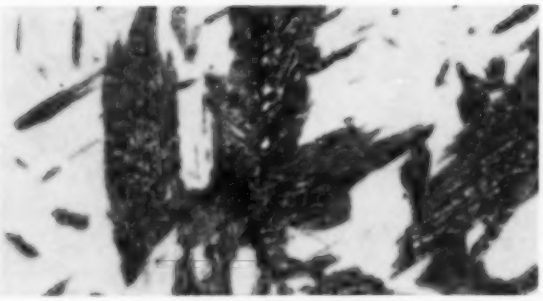

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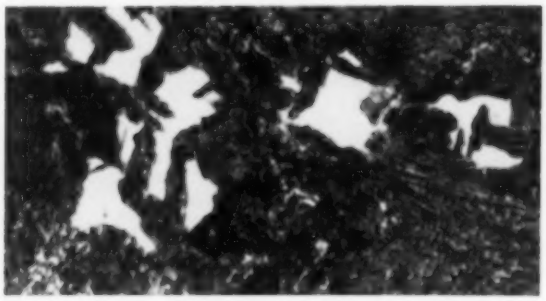

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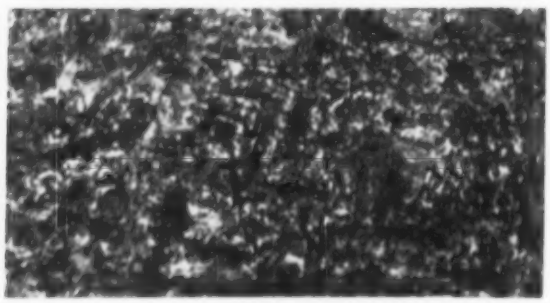

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Fig. 1—Metallographic evidence obtained in first isothermal transformation series at 800°F prepared at U. S. Steel Corp. Research Laboratory, Kearny, N. J., September 1929. Picral etch. X2000.

transformation, were topics of earnest consideration and lively debate among those pioneer physical metallurgists. How very characteristic it was of the man whose memory we honor here today, that he recognized so clearly the essential point that the fundamental reaction is the transformation of *austenite*, and that, at temperatures at which diffusion occurs, all the resultant microstructural entities are merely aggregates or mixtures of *ferrite and carbide* in various configurations! How truly modern his thinking really was in the light of our present views on these matters!

And now, more than fifty years after Howe's letter was written, austenite, its transformation behavior, and the properties of its transformation products are still matters of vital concern to ferrous metallurgists throughout the world. I propose to review briefly the development of austenite transfor-

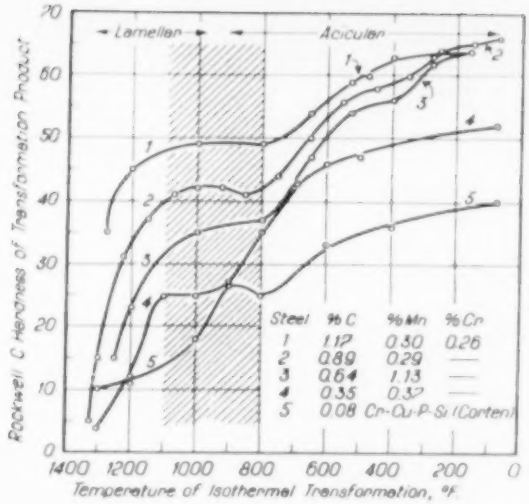

Fig. 2—Hardness of isothermal transformation products in some typical carbon and low-alloy steels.[2]

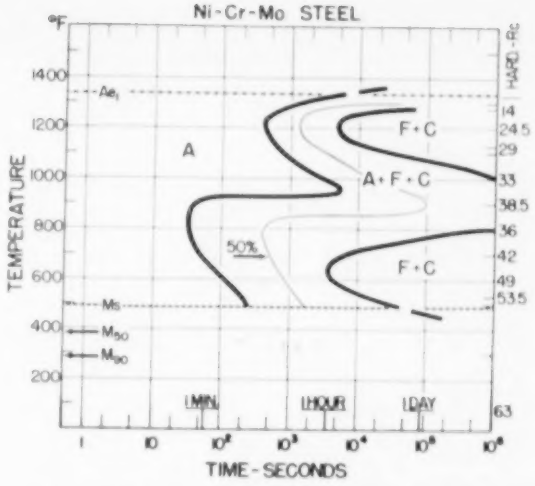

Fig. 4—Isothermal transformation diagram of Ni-Cr-Mo steel of eutectoid carbon content.

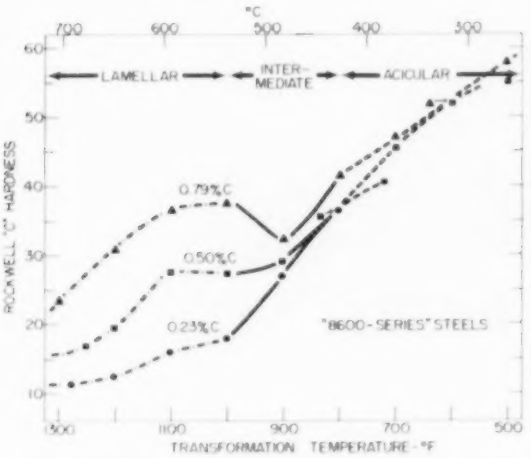

Fig. 3—Hardness of isothermal transformation products in three steels of the 8600 series containing different amounts of carbon.

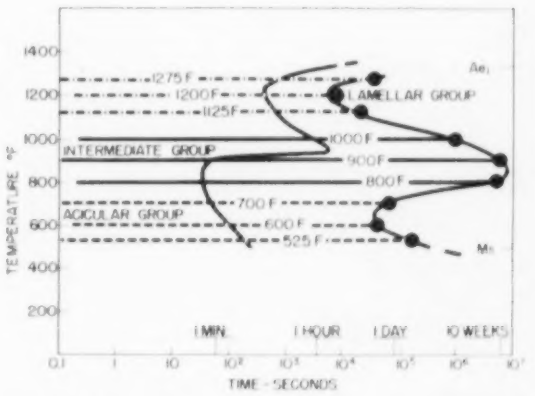

Fig. 5—Schematic representation of nine isothermal treatments used in exploring the microstructure and mechanical properties of Ni-Cr-Mo steel.

mation studies in recent years, and to discuss certain aspects of the subject, with particular reference to the all-important relationship between microstructure and mechanical properties.

Isothermal Transformation Studies

In 1929, systematic investigation of the transformation of austenite by the isothermal method was initiated at the Research Laboratory of the United States Steel Corp. at Kearny, N. J., under the direction of Dr. John Johnston and the immediate supervision of Dr. Edgar C. Bain. I had the privilege of being among those who participated in some of those early isothermal adventures.

The publication, in 1930,[1] of the results of that work touched off a series of related metallurgical investigations, both in America and abroad, that led eventually to a wholly new concept of austenite transformation.

The experimental techniques employed in isothermal transformation studies have been adequately described in the literature and need not be

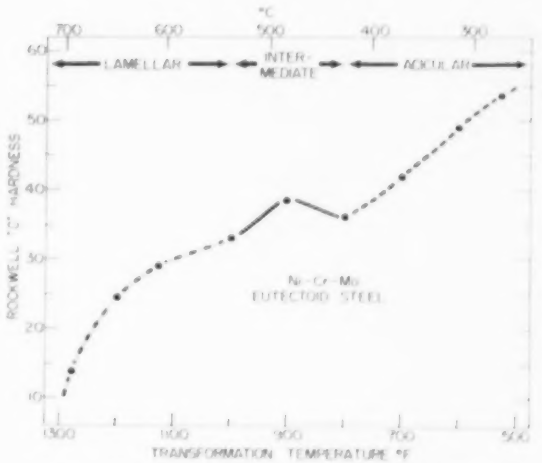

Fig. 6—Hardness of isothermal transformation products in Ni-Cr-Mo steel as influenced by transformation temperature.

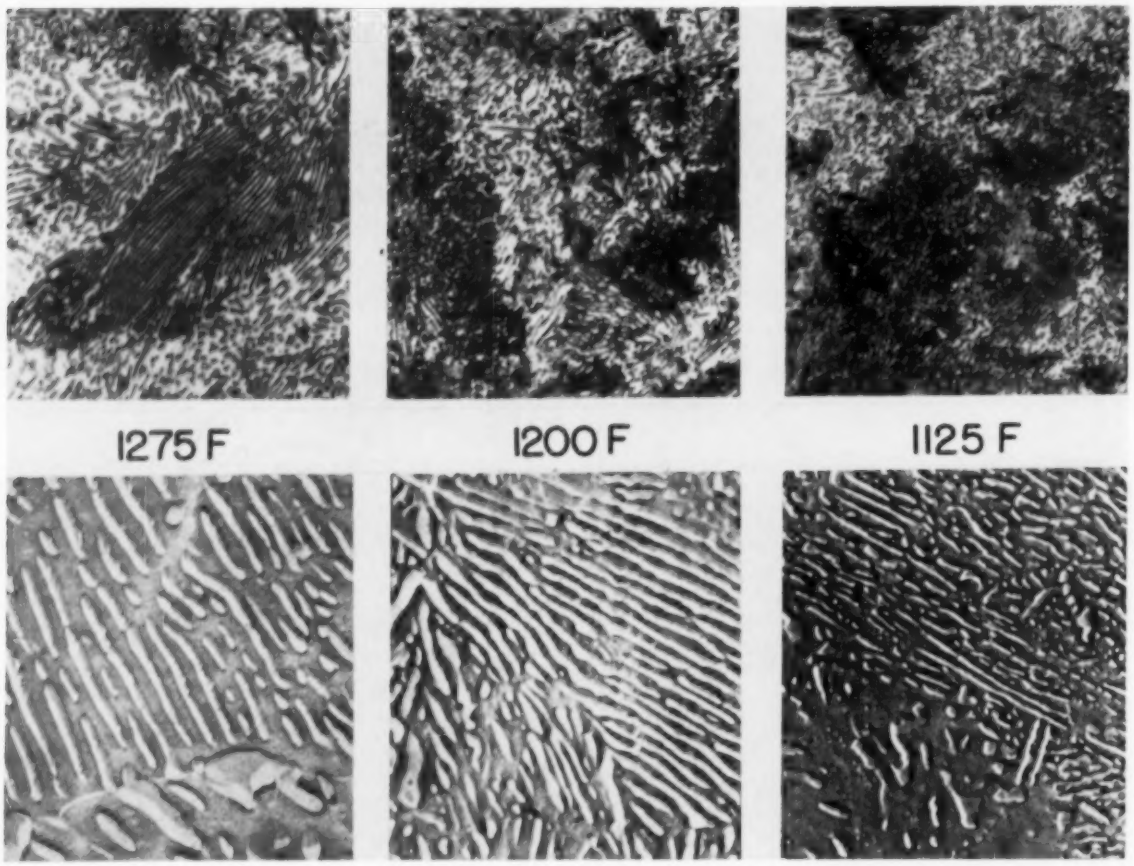

Fig. 7—Microstructure after complete isothermal transformation at 1275°, 1200°, and 1125°F in Ni-Cr-Mo steel. TOP ROW: Light micrographs. Picral etch. X2500. BOTTOM ROW: Electron micrographs. Picral etch. X12,500. Reduced approximately 10 pct for reproduction.

reviewed here. However, this may be an appropriate time to place on record the metallographic evidence of the first isothermal transformation experiment conducted at the Kearny Laboratory in September, 1929. This is shown in Fig. 1. The steel, containing 0.78 pct C and 0.36 pct Mn, was austenitized at 1650°F and isothermally transformed at 800°F, at which temperature the product of the transformation is bainite.

From that modest beginning, a tremendous volume of information on the transformation behavior of steel has been developed through the efforts of a host of investigators the world over. By 1939, ten years after the work at Kearny was started, a sizeable technical literature on the subject was already in existence. The major items of information established during that period were reviewed in the Fourteenth Campbell Memorial Lecture of the American Society for Metals presented in 1939.[3]

In the 18-year period from 1939 to the present, a vast amount of additional research on this subject has been conducted and the results made available. For example, a typical bibliography[4] of papers published through April, 1949 contained 118 items, and it made no pretense of being an exhaustive list. More than a score of additional papers have appeared during the period 1949 through 1956.

A review of this extensive literature is beyond the scope of the present lecture. However, some idea of the progressive development that was taking place in this field may be conveyed by noting the several excellent compilations of isothermal transformation diagrams that were published during that 18-year period. Since these compilations are based upon the painstaking accumulation of experimental data, they serve as a reliable measure of the extent of creative effort that has been devoted to this subject.

In 1943 the first comprehensive compilation of isothermal transformation diagrams covering 47 different steel compositions was published and distributed by the United States Steel Corp. under the title *Atlas of Isothermal Transformation Diagrams*.[5] This was reissued in 1951 in revised and expanded form, covering 87 different compositions.[6] In 1945, Morral[7] published an index and a proposed scheme of classification of isothermal diagrams for some 192 compositions for which data were then available. In 1947, the International Nickel Co. published diagrams for 24 nickel alloy steels;[8] in 1949, the Iron and Steel Institute (British) published its *Atlas of Isothermal Transformation Diagrams of B. S. En Steels*[9] covering 24 steel compositions, and this was revised and expanded in 1956.[9] In 1950, the Mond Nickel Co. Ltd. issued a compilation of diagrams for 13 nickel alloy steels[10] with an expanded edition in 1952.[10] In 1953, the Institute de Recherches de la Siderurgie (IRSID) published a compilation covering 30 French carbon and alloy steels[11] and an en-

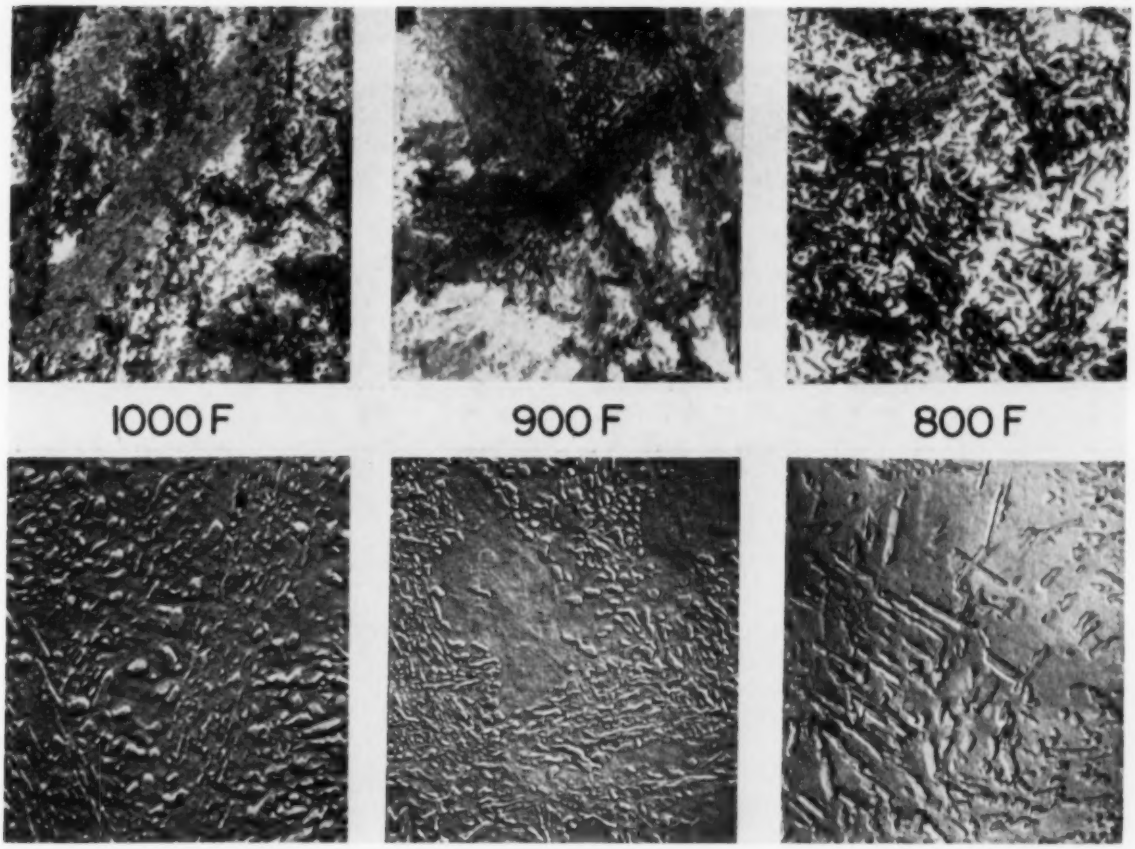

Fig. 8—Microstructure after complete isothermal transformation at 1000°, 900°, and 800°F in Ni-Cr-Mo steel. TOP ROW: Light micrographs. Picral etch. X2500. BOTTOM ROW: Electron micrographs. Picral etch. X12,500. Reduced approximately 10 pct for reproduction.

larged edition was issued in 1956. Also in 1953, a *Supplement*[17] to the United States Steel Corp.'s *Atlas* was issued, comprising over 400 facsimile reproductions of isothermal transformation diagrams published in the United States, Great Britain, and Canada prior to 1952. In 1954, the Max-Planck Institute für Eisenforschung, in cooperation with the Vereins Deutscher Eisenhuttenleute in Germany, published an extensive *Atlas for the Heat Treatment of Steel*,[18] which was expanded during 1956.

In the light of these numerous compilations, supported by the contributions of hundreds of individual investigators, it is evident that austenite transformation studies, including both isothermal and continuous cooling techniques, have had a profound and permanent influence on the art and science of heat treatment.

Ferrite-Carbide Aggregates

Let us recall, for a moment, Professor Howe's keen observation that, in considering the transformation processes in steel, it is "much simpler to confine ourselves to the end stages—*austenite* and *ferrite plus cementite*" or, in other words, to austenite and ferrite-carbide aggregates.

Today, metallurgists generally recognize that the nature and characteristics of these ferrite-carbide aggregates determine the useful mechanical properties of steel. The character of these aggregates can be varied within wide limits by appropriate heat-treating procedures so as to produce the many different combinations of strength, ductility, and toughness that make steel such a versatile engineering material.

Isothermal transformation studies have established the fact that ferrite-carbide aggregates which form from austenite above the M_s temperature divide themselves into two broad categories of microstructure, depending upon their microscopic appearance and temperature range of formation. These are 1) the lamellar or pearlitic group of structures, and 2) the acicular or bainitic group of structures.

In an intermediate temperature range there is a transition from the clear-cut lamellar to the acicular mode of transformation and in this range the microstructure and corresponding mechanical properties, particularly in alloy steels, often exhibit interesting special features, as will presently be discussed.

In general, within either the pearlitic or bainitic group, the dispersion of carbide in the ferrite becomes finer, and hardness and strength increase as transformation temperature is lowered. This is illustrated, in terms of hardness, in Fig. 2, reproduced from an earlier publication.[2] The curves show, for a number of carbon and alloy steels, the increase in Rockwell C hardness with decreasing isothermal transformation temperature. In several of these curves there is a temperature range, indicated by the shaded band, in which the hardness fails to in-

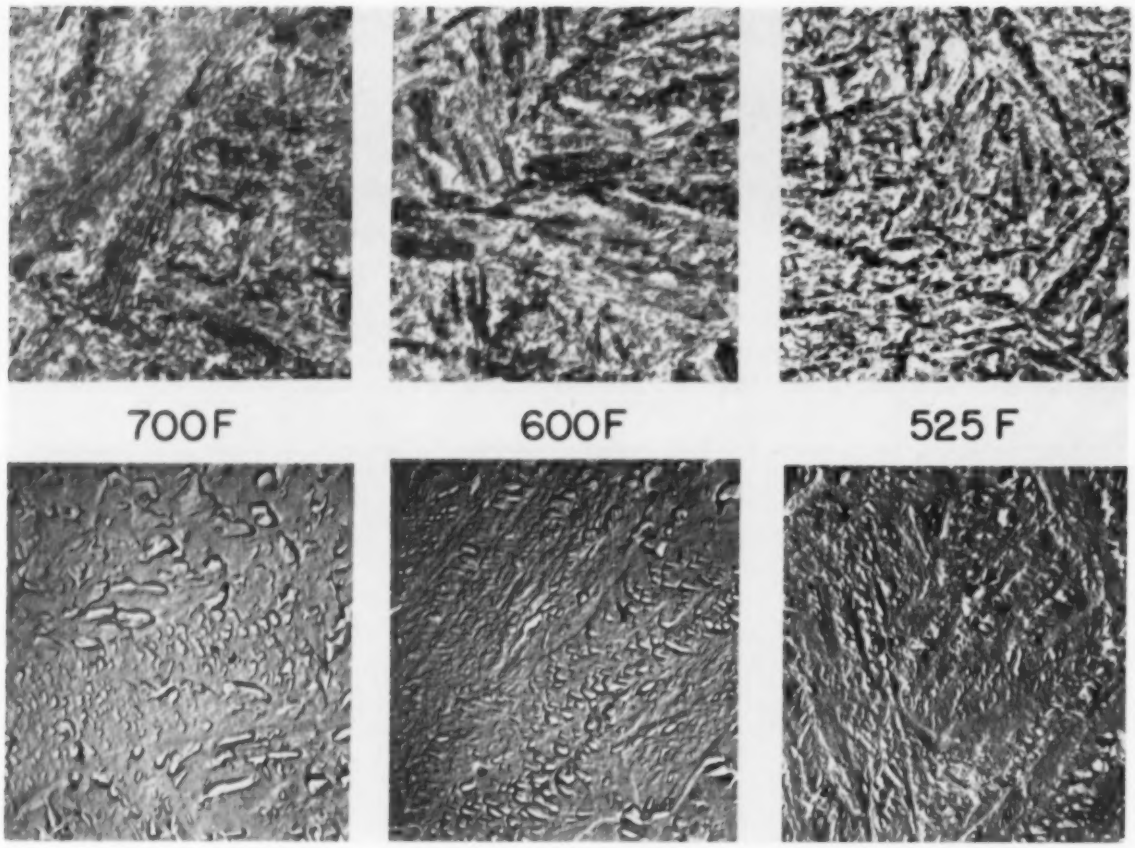

Fig. 9—Microstructure after complete isothermal transformation at 700°, 600°, and 525°F in Ni-Cr-Mo steel. TOP ROW: Light micrographs. Picral etch. X2500. BOTTOM ROW: Electron micrographs. Picral etch. X12,500. Reduced approximately 10 pct for reproduction.

crease—in fact, in some cases, it actually decreases in this restricted range as transformation temperature is lowered. Note that this anomalous hardness behavior is associated with the temperature range in which the microstructure changes from the lamellar to the acicular type. This has recently been confirmed by some of my associates[6] in a series of alloy steels of graded carbon content in which the effect appears to be accentuated by increase in carbon content, as illustrated in Fig. 3.

These peculiar hardness manifestations were discussed briefly in a previous publication[5] and have continued to be of interest in developing a better understanding of the relationship between microstructure and mechanical properties.

As part of a long-range program to learn more about these relationships, a study of the microstructure and mechanical properties of a Ni-Cr-Mo steel of eutectoid carbon content has been under way for some time at the Edgar C. Bain Laboratory for Fundamental Research of the United States Steel Corp. at Monroeville, Pa. The results of this investigation have been made available to me, most generously, for presentation as part of this lecture.

Microstructure and Mechanical Properties of Isothermally Formed Ferrite-Carbide Aggregates

For this investigation it was considered essential to select a steel of sufficiently high hardenability to assure uniform microstructure in the heat-treated mechanical test specimens. In addition, freedom from the complicating effects of proeutectoid constituents was desired. A Ni-Cr-Mo steel of eutectoid carbon content which met these requirements was chosen and all the material used in the investigation was taken from a single bloom of a commercial, open hearth production heat, forged and rolled to 1¼ in. diam bars. The chemical composition of the material is given in Table I.

The isothermal transformation diagram was determined by the metallographic method, using an austenitizing temperature of 1700°F (ASTM Grain Size No. 4 to 5). The *Ae*, temperature and the temperature range of martensite formation also were determined. These data are shown in Fig. 4. The steel exhibits the typical transformation characteristics and high hardenability of an alloy steel of the 4300 class.

Fig. 5 shows the nine isothermal transformation temperatures selected for exploring the microstructural characteristics and mechanical properties of this steel. The three upper temperatures (1275°, 1200°, and 1125°F) represent the range in which lamellar or pearlitic structures form from austenite. The three lower levels (700°, 600°, and 525°F) are in the range in which typical acicular or bainitic structures form. The three intermediate temperatures (1000°, 900°, and 800°F) represent the range within which the microstructure changes from the lamellar to the acicular type and where the discon-

Fig. 10—Microstructure after 50 pct isothermal transformation at TOP: 1000°, CENTER: 900°, and BOTTOM: 800°F in Ni-Cr-Mo steel. Nital etch. X2500. Reduced approximately 50 pct for reproduction.

Fig. 11—Microstructure illustrating two-stage isothermal transformation at 900°F in Ni-Cr-Mo steel. TOP: 10 pct transformation; CENTER: 50 pct transformation; and BOTTOM: 100 pct transformation. Nital etch. X2500. Reduced approximately 50 pct for reproduction.

tinuity in hardness trend occurs with decrease in transformation temperature. This hardness discontinuity in the Ni-Cr-Mo steel involved here is shown in Fig. 6.

Attention is directed to the scheme adopted for depicting the lamellar, intermediate, and acicular groups of structure; that is, a dot-dash line for lamellar, a solid line for intermediate, and a dash line for acicular. As mentioned earlier, the intermediate region between distinctly lamellar and distinctly acicular structures is of particular interest because of the special microstructural and mechanical property features associated with it.

Microstructure

Figs. 7, 8, and 9 illustrate the microstructures representative of complete isothermal transformation at each of the nine temperatures selected for investigation. The micrographs show representative fields for each temperature level as revealed by the conventional light microscope at a magnification of X2500, and by the electron microscope at X12,500.

Fig. 7 shows the three structures comprising the lamellar group. As would be expected, the pearlite becomes finer and the structure less distinctly lamellar as the transformation temperature decreases. By comparison with the usually regular pearlite of most carbon steels, this series illustrates the tendency of pearlite in alloy steels to be less perfectly lamellar than in plain carbon steels.

Fig. 8 shows the three microstructures comprising the intermediate group; namely, those formed at 1000°, 900°, and 800°F, the temperature range within which the hardness anomaly occurs. As transformed at 1000°F the lamellar characteristics are scarcely recognizable except in isolated areas, and at 900°F they have practically disappeared. At these two temperatures the ferrite-carbide aggregate tends to assume an acicular rather than the nodular configuration usually found in carbon steels transformed at these temperatures.

At the 800°F level, the structure undergoes a rather marked coarsening which is reflected in the discontinuity in the hardness trend previously mentioned. After completion of transformation, the structure consists of roughly acicular groups of rod-like carbides in the ferrite matrix. It is interesting to note that this 800°F product resembles, in some respects, the coarser pearlitic structures. Possibly one basic difference in the form of the carbides in pearlite and bainite may be that they are plate-like in pearlite and rod-like in bainite. Microscopic examination of etched plane surfaces does not resolve this question with certainty.

Fig. 9 shows microstructures representative of the three lower transformation temperatures—700°, 600°, and 525°F, where the product is definitely bainitic. In general, the fineness and uniformity of

Table I. Chemical Composition of Ni-Cr-Mo Eutectoid Steel

Element	Pct	Element	Pct
Carbon	0.57	Silicon	0.30
Manganese	0.82	Nickel	1.16
Phosphorus	0.016	Chromium	1.07
Sulfur	0.019	Molybdenum	0.28

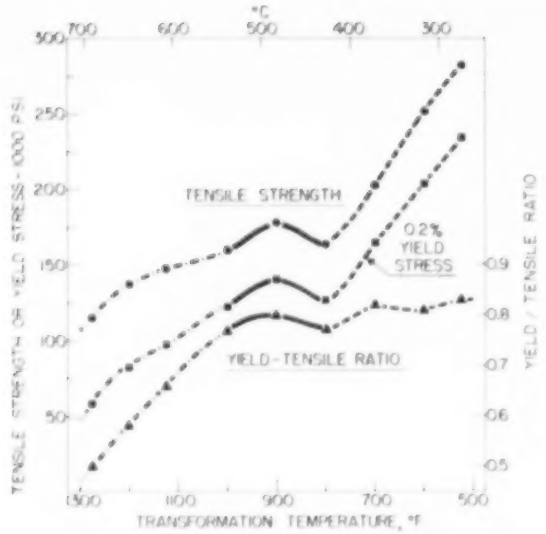

Fig. 12—Relationship of strength to transformation temperature in isothermally transformed Ni-Cr-Mo steel.

carbide dispersion increase with lowering of the transformation temperature.

At this point it may be helpful to take a closer look at the transformation behavior and structures characteristic of the intermediate temperature range, 1000° to 800°F. The acicular nature of these structures can be most easily recognized in partially transformed specimens, as illustrated in the light micrographs of Fig. 10, showing 50 pct transformation at 1000°, 900°, and 800°F. The rapid-etching, acicular aggregates that form at 1000° and 900°F might conceivably be thought of as extremely fine pearlites which, due to the influence of alloy content, tend to assume an acicular configuration rather than the nodular form usually encountered in plain carbon steels at these temperatures.

The formation of the rapid-etching, acicular aggregate at 900°F is preceded by the separation of a roughly acicular type of ferrite. The transformation then goes to completion with the formation of the rapid-etching aggregate. These two transformation stages were described in a previous publication,[7] and are illustrated in Fig. 11. The acicular ferrite undoubtedly corresponds to what Hultgren[6] designated as probainitic ferrite or *paraferrite*, a constituent which has been discussed by a number of other investigators.[8]

Having established a correlation between hardness and microstructure in this steel, let us now see what happens to some of the other mechanical properties when the steel is transformed isothermally within the temperature range 1275° to 525°F.

Mechanical Properties

Tensile and impact properties were determined on specimens austenitized at 1700°F (Grain Size 4 to 5) and isothermally transformed at each of the nine temperatures used for the microstructural studies. Room-temperature tensile tests were conducted using 0.25-in. diam, 1-in. gage-length specimens. For the impact tests, standard *V*-notch Charpy specimens were broken over a suitable range of temperatures and the energy absorbed was plotted against test temperature. From these data, a comparative toughness criterion based upon the temperature corresponding to an average impact value of 15 ft-lb was chosen; this criterion is used throughout the following discussion.

Fig. 12 shows the room-temperature strength properties plotted against isothermal transformation temperature. The values for tensile strength, 0.2 pct offset yield stress, and yield-tensile ratio follow the same general pattern as the hardness values previously shown. Strength increases as transformation temperature decreases through the pearlite-forming range—and even on down to 900°F where the microstructure has lost most of its recognizable lamellar characteristics. At 800°F there is an unmistakable decrease in strength corresponding to the drop in hardness associated with this level. Strength again rises as transformation temperature decreases below 800°F. Thus we find that strength, hardness, and microstructure follow a mutually consistent pattern.

Fig. 13 shows the room-temperature ductility and toughness properties plotted in a similar manner. It is seen that reduction of area values increase as transformation temperature is lowered through most of the pearlite-forming range, and then fall off appreciably in the intermediate range, reaching a minimum in the vicinity of 900°F. The values rise again as bainite is formed in the 700° to 600°F range, eventually decreasing as high-hardness bainite is reached at the 525°F level.

Elongation values decrease more or less regularly with transformation temperature over the whole range investigated, with essentially no evidence of irregularity in the intermediate region. This is not surprising since it is generally recognized that elongation is not a particularly structure-sensitive property.

Toughness decreases markedly in the intermediate region, contrasting sharply with the better toughness exhibited by the pearlitic and bainitic structures formed at immediately higher and lower transformation temperatures, respectively.

It is interesting to note that, within the pearlitic series, reduction of area and toughness improve with increasing fineness of pearlite. The improve-

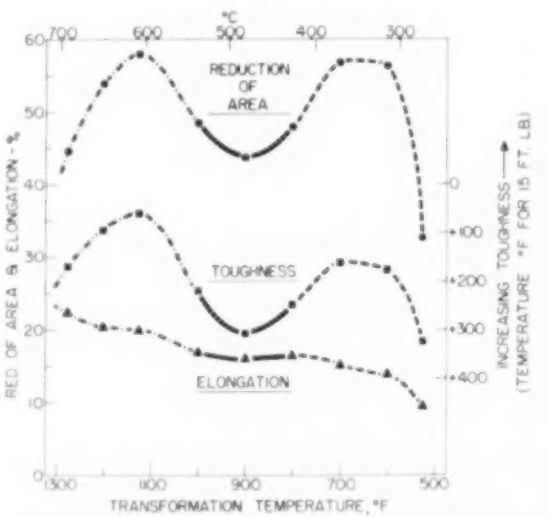

Fig. 13—Relationship of ductility and toughness to transformation temperature in isothermally transformed Ni-Cr-Mo steel.

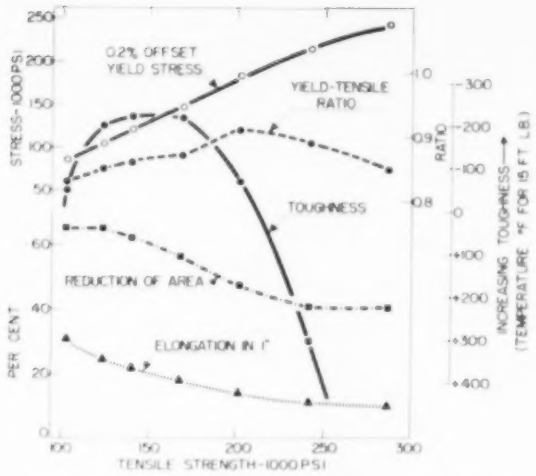

Fig. 14—Mechanical properties of quenched-and-tempered Ni-Cr-Mo steel plotted against tensile strength.

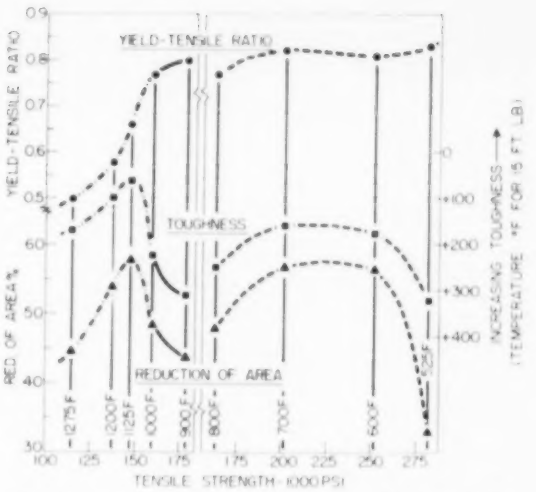

Fig. 15—Selected mechanical properties of isothermally transformed Ni-Cr-Mo steel plotted against tensile strength.

ment in ductility accompanies an increase in strength, contrary to the usual relationship between these properties. This may be the net result of finer carbide dispersion and smaller ferrite grain size in the finer pearlites.

While the present investigation was limited to a single steel, the accumulated evidence of many isothermal transformation studies on a wide variety of steels indicates that the observed microstructural and mechanical property effects in the intermediate region do not constitute an isolated instance, but probably represent a rather general case, at least among alloy steels. Gensamer and co-workers,[11-13] investigating plain carbon and manganese steels, obtained results which are generally consistent with the present findings.

Comparison of Properties: Isothermal Vs Quench-and-Temper Treatment

It was thought desirable to compare the mechanical properties of the isothermally transformed steel with the properties of the same steel fully quench-hardened to martensite and tempered so as to encompass the same range of strength and hardness. Hence a quench-and-temper series was prepared and tested. The following comparisons reveal the relative merits of the two series of ferrite-carbide aggregates—one having formed directly out of austenite, the other having been derived from martensite. In these comparisons, the properties are plotted against tensile strength—selected as a factor common to both the isothermal and the quench-and-temper series.

Fig. 14 shows the properties of the quench-and-temper series only, plotted as a function of tensile strength. Ductility decreases regularly with increase in strength, and there is a pronounced drop in toughness at the higher strength levels. Irregularities, such as those encountered in the intermediate region of the isothermal series, are absent in these curves.

The discontinuity in the strength trend in the isothermal series creates a problem in plotting properties of this series as a function of strength, while at the same time maintaining the orderly sequence of transformation temperature. This was handled in the manner shown in Fig. 15 for three selected properties. The isothermal transformation temperature involved in each case is shown near the bottom of the chart, which is divided into two segments. A portion of the horizontal strength scale of each segment is duplicated in the vicinity of the break in the chart. This permits getting around the circumstance that the strength of specimens isothermally transformed at 800°F falls between that of specimens treated at 900° and at 1000°F.

The difference in properties of the isothermal series and the quench-and-temper series is illustrated in Figs. 16 through 20. In each chart the middle point on the quench-and-temper series curve is common to both segments of the chart.

Fig. 16 shows that the 0.2 pct offset yield stress values for the isothermal series are generally lower than those for the quench-and-temper series, although they approach each other at the highest strength level. Fig. 17 shows a similar comparison for the yield-tensile ratio values. The pearlitic structures have a consistently lower ratio than the quench-and-temper structures of comparable strength but, at the highest strength, bainite is practically equivalent to tempered martensite.

Figs. 18 and 19 show the superior ductility of the quench-and-temper structures as compared to coarse pearlite, and a reversal of this relationship at the higher strength levels where bainite shows generally superior ductility, except at the very highest strength.

Fig. 20 shows a similar comparison in terms of the selected toughness criterion. It is clear that the pearlites are definitely inferior to the quench-and-temper structures and that the bainites are superior at the high strength levels.

Ferrite-Carbide Aggregates Formed During Continuous Cooling

The foregoing comparisons have demonstrated the difference in mechanical properties of two series of ferrite-carbide aggregates of fundamentally different origin—one resulting directly from isothermal transformation of austenite, the other from transformation to martensite followed by tempering. With the exception of lower bainite, the properties of the isothermally formed aggregates were shown

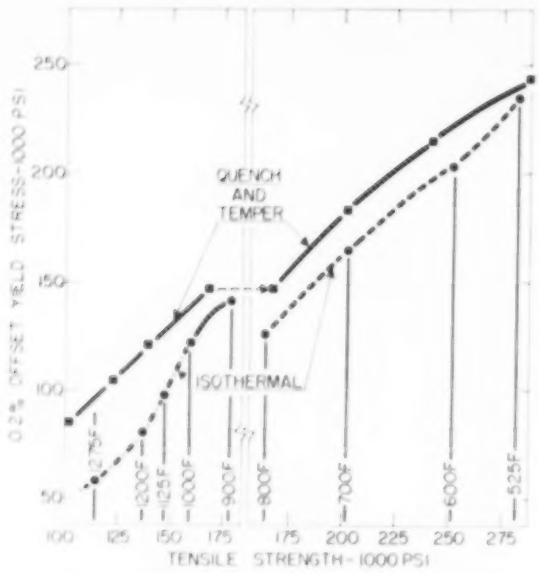

Fig. 16—Comparison of yield stress in Ni-Cr-Mo steel as quenched and tempered and as isothermally transformed.

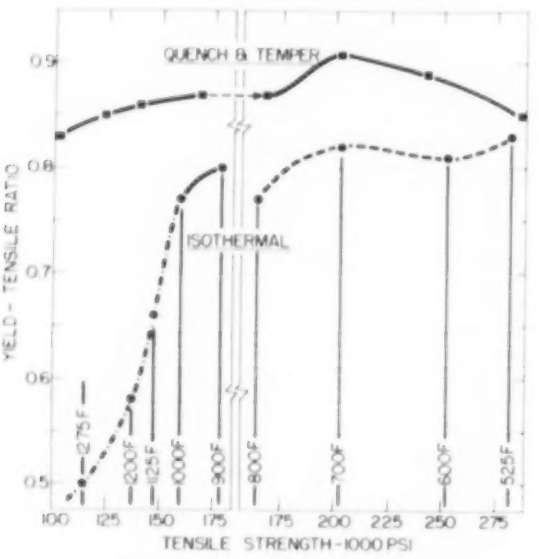

Fig. 17—Comparison of yield-tensile ratio in Ni-Cr-Mo steel as quenched and tempered and as isothermally transformed.

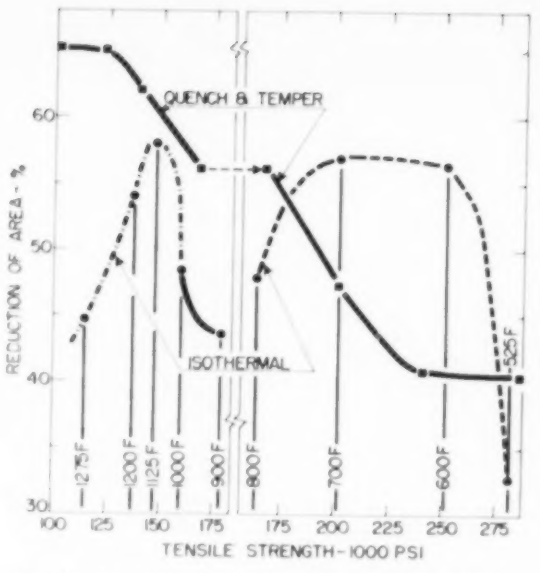

Fig. 18—Comparison of reduction of area in Ni-Cr-Mo steel as quenched and tempered and as isothermally transformed.

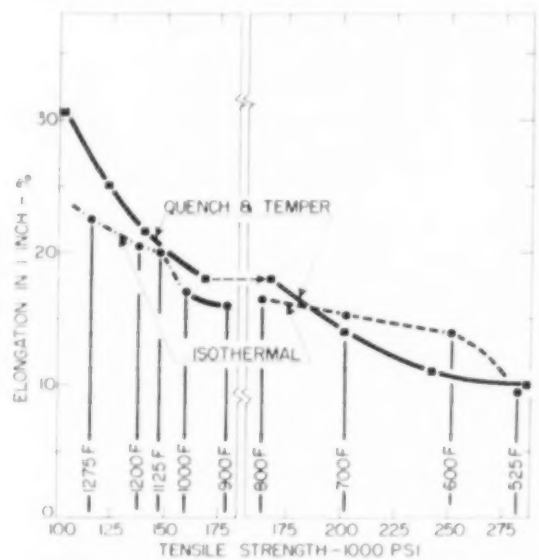

Fig. 19—Comparison of elongation in Ni-Cr-Mo steel as quenched and tempered and as isothermally transformed.

to be generally inferior to those of tempered martensite.

Most practical heat treatments involve some form of continuous cooling, usually with subsequent tempering. Thus, the final structure after heat treatment consists of tempered martensite, or mixtures of tempered martensite and tempered direct transformation products. While 100 pct tempered martensite is frequently the goal of heat treatment, practical considerations often make it necessary to accept such mixtures, particularly where large masses of material are involved. The question naturally arises as to whether the presence of these direct transformation products result in substantial damage to mechanical properties. A few data relating to this question were obtained for the Ni-Cr-Mo steel in this investigation.

Mechanical test specimens were continuously cooled from an austenitizing temperature of 1700°F, at each of five different rates. These cooling rates were selected to develop structures ranging from approximately 100 pct martensite to 100 pct pearlite. All specimens were tempered at 1200°F for 20 hr to obtain essentially a common tensile strength as a basis for comparison.

Fig. 21 shows the five cooling rates used, expressed as the average rate between the Ae_1 and M_s temperatures. While not quantitatively applicable, the isothermal diagram is also shown, in view of the fact that, up to this point, many of the data on this steel have been presented in terms of isothermal transformation behavior.

The temperature range within which transformation is presumed to have occurred during continu-

ous cooling is shown by characteristic cross-hatching along each cooling curve, with particular reference to the three categories of structure—lamellar, intermediate, and acicular. The percentages of the various microconstituents found in the specimens after continuous cooling are indicated in the lower portion of the chart. It is significant that, although the five cooling rates yielded structures covering the whole range from essentially 100 pct to 0 pct martensite, the proportion of intermediate structures never exceeded 5 pct.

The mechanical property test results are summarized in Fig. 22, in which the properties are plotted against cooling rate. It is seen that the chosen tempering treatment did, indeed, result in comparable tensile strength throughout the series, except for the specimens cooled at the slowest rate—and even they are not greatly out of line. All other properties showed some deterioration as the cooling rate became slower and the percentage of martensite decreased. However, it was not until the structure became predominantly pearlitic at the two slowest cooling rates that the properties showed marked inferiority to those for tempered martensite.

Thus, in this particular steel, tempered at a relatively high temperature, failure to achieve a 100 pct martensitic structure entailed only a small sacrifice in properties, except when very large amounts of pearlite were formed as a result of slow cooling. This is obviously due to the absence of substantial amounts of intermediate ferrite-carbide aggregates which, as shown earlier, have definitely inferior properties. With a steel of different carbon or alloy content, these relationships would certainly be altered. Undoubtedly, the more hypoeutectoid the composition, the greater would be the tendency to form proeutectoid ferrite and intermediate temperature range aggregates, and the more adverse the effect upon mechanical properties.

It is often necessary to select alloy steels for heavy forgings and the like, which are sometimes unavoidably cooled at rates slower than the so-called *critical cooling rate;* and yet optimum mechanical properties are always desired. This calls for the proper combination of carbon and alloying elements to *retard* the formation of ferrite, pearlite, and intermediate range structures, and to *promote* the formation of lower temperature acicular products, or combinations of these with martensite. Different alloy steels, even though substantially alike in hardenability, as ordinarily defined, may differ significantly in these respects. A better understanding of the various factors influencing the formation and properties of intermediate range structures should help in designing better alloy steels for the future.

Recapitulation

The experimental data presented in this lecture have dealt with the microstructure and mechanical properties of ferrite-carbide aggregates in an alloy steel of eutectoid carbon content. For presentation purposes, these aggregates, as formed directly from austenite by isothermal transformation, have been grouped into categories designated as *lamellar, intermediate,* and *acicular,* depending upon their general microstructural appearance which, in turn, is related to the temperature range in which they form.

Within the lamellar and acicular groups, there is a progressive change in microstructure and properties as the transformation temperature increases or

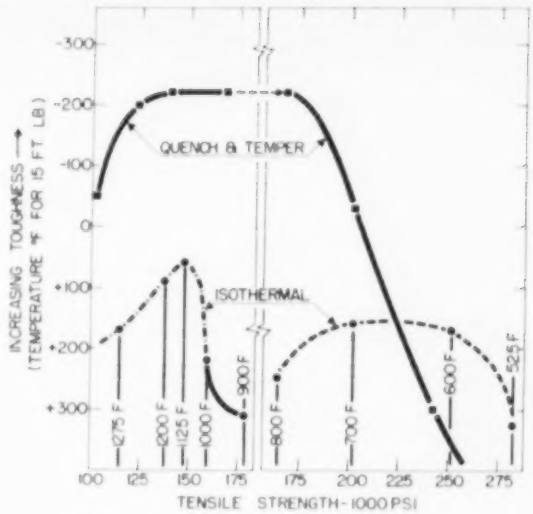

Fig. 20—Comparison of toughness in Ni-Cr-Mo steel as quenched-and-tempered and as isothermally transformed.

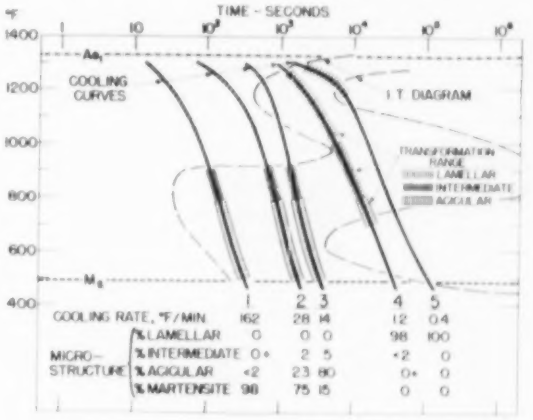

Fig. 21—Cooling rates and resulting structures involved in continuous cooling studies of Ni-Cr-Mo steel.

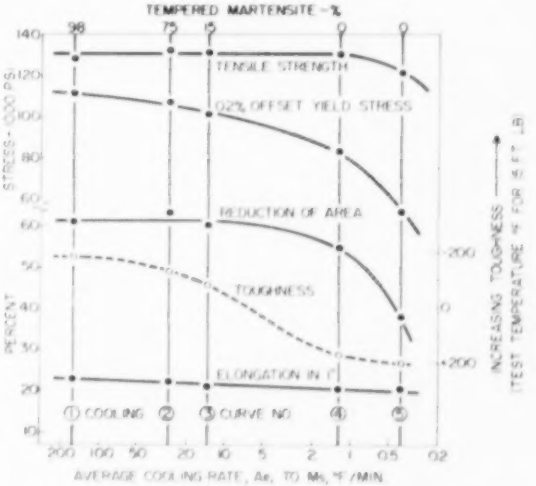
TEMPERED MARTENSITE - %
TENSILE STRENGTH
0.2% OFFSET YIELD STRESS
REDUCTION OF AREA
TOUGHNESS
ELONGATION IN 1"
STRESS - 1000 PSI
PERCENT
INCREASING TOUGHNESS → (TEST TEMPERATURE °F FOR 45 FT LB)
① COOLING ② ③ CURVE NO. ④ ⑤
AVERAGE COOLING RATE, Ae1 TO Ms, °F/MIN

Fig. 22—Mechanical properties of Ni-Cr-Mo steel as cooled continuously at the five different rates shown in Fig. 21 and tempered 20 hr at 1200°F.

decreases. The intermediate group superficially suggests a discontinuity in the regularity of this relationship, although conceivably it may represent little more than a series of mixtures of the other two structures, pearlite and bainite. The mechanical properties of aggregates formed in the intermediate range are relatively inferior to those of fine pearlite and of bainite, although some of these properties are substantially what might be predicted from mixtures of the two structures. Nevertheless, the implication is clear that both lamellar and intermediate structures should be avoided if optimum mechanical properties are to be achieved.

The properties of isothermally formed structures have been compared with those of tempered martensite of comparable strength and hardness. With the exception of lower bainite, tempered martensite exhibits consistently superior mechanical properties.

With the particular steel involved in this investigation, continuous cooling studies indicated that the undesirable intermediate structures did not form in sufficient amounts to have an appreciably adverse effect on mechanical properties. This would not necessarily hold true for other combinations of carbon and alloying elements.

In the heat treatment of relatively large masses of steel, the formation of intermediate structures during cooling is an ever-present possibility. The future development of better alloy steels for many critical applications would seem to depend upon a more searching analysis, and systematic study of the influence of carbon and alloying elements—both individually and in various combinations, upon the transformation characteristics and mechanical properties of these intermediate structures.

A wealth of information has been accumulated through studies of austenite transformation, by one technique or another, since our first isothermal experiment was performed in 1929. Still, the utility of this approach to heat treatment problems is far from exhausted, and the potential rewards, in the form of improved and more uniform properties in heat-treated steel products, are still exceedingly high.

Acknowledgments

It is my pleasant duty to acknowledge the many valuable contributions which my associates at the Edgar C. Bain Laboratory for Fundamental Research of the United States Steel Corp. have made in developing experimental and illustrative material, and in supplying helpful advice during the preparation of this lecture. I should like to mention particularly the following individuals who took part in these activities: R. W. Baughman, R. M. Fisher, R. A. Grange, J. J. Harrington, Mrs. E. P. Hartner, R. E. Jungo, S. Lentz, K. H. Lohse, G. D. Marsico, R. L. Rickett, W. B. Seens, A. Szirmae, and J. R. Vilella. I also wish to acknowledge gratefully the cooperation of J. B. Austin and R. H. Aborn in making this work of my colleagues available for presentation in this form.

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Technical Note

Peritectoid Transformation in Ag-Al Alloys

by C. W. Spencer, R. J. Knight, and F. N. Rhines

A metallographic study has been made of the peritectoid transformation as it occurs in two Ag-Al alloys, containing 6.0 and 6.9 wt pct Al, respectively. After equilibrating at 475°C, these alloys were transformed isothermally just below the peritectoid temperature which lies at about 450°C.[1-4]

Peritectoid transformation in this alloy system consists in the reaction of α and ζ to form μ. The crystal structures of the α, μ, and ζ phases have been determined as face-centered-cubic, β manganese, and hexagonal-close-packed, respectively. At the peritectoid temperature their equilibrium compositions are approximately 5.85, 7.02, and 7.24 wt pct (19.92, 23.2, and 23.8 atomic pct) aluminum.[1,2] The transformation might be expected to occur principally at the interface between the α and ζ, but such is not the case. Instead, the major part of the transformation occurs by the direct (and perhaps initially diffusionless) conversion of ζ to μ. The composition range of the forming μ nearly overlaps that of the parent ζ at the temperature of transformation[3] so that little, if any, composition change is required. Transformation proceeds by the nucleation of μ at points upon the external surface of the sample and sweeps through the ζ phase, leaving the α initially almost undisturbed. Subsequently, the α phase participates in the transformation by being partly or totally converted to μ.

Specimens approximately 1/4 x 1/4 x 1/16 in. were cut from cast ingots, previously equilibrated 68 hr at 588°C. The specimens were held for 3 hr at

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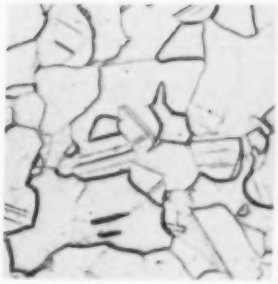

Fig. 1—6.0 wt pct Al, quenched from 475° C, in the $\alpha + \zeta$ phase field. Heavily outlined areas are ζ, twinned grains are α.

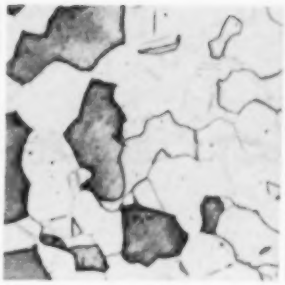

Fig. 2—6.0 wt pct Al, isothermally transformed 1 min at 428°C; α (twinned), ζ (heavily outlined), and μ (dark).

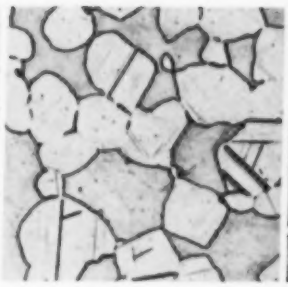

Fig. 3—6.0 wt pct Al, isothermally transformed 4 min at 428°C; α (light) and μ (dark).

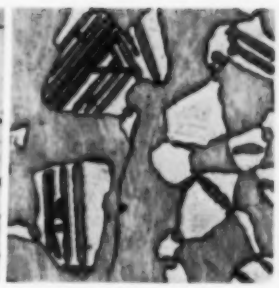

Fig. 4—6.0 wt pct Al, isothermally transformed 17 hr at 428°C; α (light) and μ (dark).

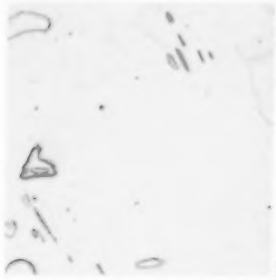

Fig. 5—6.9 wt pct Al, quenched from 475°C, in the $\alpha + \zeta$ phase field. Small areas are α; matrix is ζ.

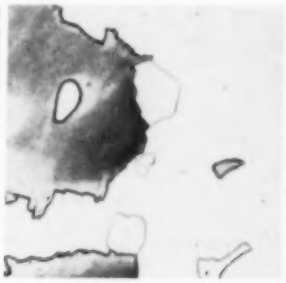

Fig. 6—6.9 wt pct Al, isothermally transformed 2½ min at 428°C; α (small white islands), ζ (large white area), and μ (dark).

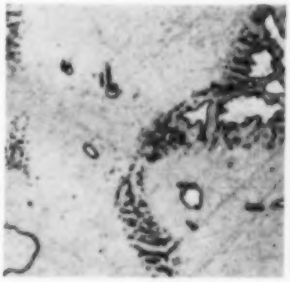

Fig. 7—6.9 wt pct Al, isothermally transformed 18 min at 428°C; α (light islands, rounded outline), ζ (white islands, jagged outline), and μ (dark).

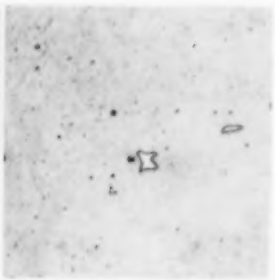

Fig. 8—6.9 wt pct Al, isothermally transformed 17 hr at 428°C; α (light) and μ (dark).

All specimens were etched in a freshly combined mixture of two solutions, consisting of 1 part of a solution containing 6 g $K_2Cr_2O_7$, 20 cu cm H_2SO_4, 12 cu cm NaCl (saturated solution), and 300 cu cm H_2O to 5 parts of a solution containing 40 g chromic acid and 360 cu cm H_2O. X150. Reduced approximately 25 pct for reproduction.

568°C, after which they were cooled slowly to 475°C. They were then immersed in a salt bath for isothermal transformation.

The structure of the 6.0 wt pct Al alloy as quenched from 475°C in the $\alpha + \zeta$ phase field is shown in Fig. 1. A dark etching boundary separates the two phases; the α phase is twinned. Upon isothermal transformation at 428° ±2°C, the μ phase is first observed at times of 30 sec to 1 min. Usually two or three points of nucleation are found in any one polished cross section, although in some specimens the reaction was observed to proceed almost to completion on the basis of one point of nucleation. One point of nucleation is sufficient if the ζ phase is continuous, as is the case when the dihedral angle is less than 60°.[4] The progress of transformation in 1 min at 428°±2°C is shown in Fig. 2. The sample was quenched from the reaction temperature for inspection. The ζ is completely consumed by the μ in approximately 4 min.

Soon after the ζ to μ reaction has gone to completion, μ is observed to precipitate in the α twin boundaries, as is shown in Fig. 3. This reaction is slow, taking several hours to go to completion. After 17 hr the structure, as shown in Fig. 4, is essentially at equilibrium.

The 6.9 wt pct Al alloy, when quenched from 475°C, is composed of α distributed throughout a ζ matrix, see Fig. 5. As in the previously described case, nucleation of μ occurs at a few points upon the external surface and the transformation proceeds through the continuous ζ phase, as shown in Fig. 6. Many cracks develop in the brittle μ during the transformation (or subsequent quenching). In later stages the interface between the advancing μ and the parent ζ becomes serrated, as is shown in Fig. 7. The ζ to μ transformation goes to completion in approximately 30 min. After 17 hr the structure is composed almost entirely of μ, with a few small particles of α remaining, Fig. 8.

X-ray powder patterns taken of the structures shown in Figs. 5, 7, and 8 (the 6.9 wt pct Al alloy) have confirmed the presence of the phases discussed at the various stages of the transformation. No transitional phases other than μ, which may not be of equilibrium composition, are present. The hexagonal-close-packed ζ has a c/a ratio of 1.629; the c value is 4.670A. The complex cubic μ phase has an a value of 6.945A.

This mode of transformation is probably fairly common among peritectoid systems. Cases in which the composition range of the low temperature phase overlaps that of one of the high temperature phases are numerous. The *Metals Handbook* indicates this condition in many systems, including Ag-Cd, Ag-Zn, Cb-Fe, Cu-Si, Ni-Si, Ni-Zn, and Sn-Sb.[5]

Acknowledgment

The authors wish to thank James J. Feenan, Metals Research Laboratory, Carnegie Institute of Technology, for performing the X-ray work.

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Thermodynamic Properties of CS And Solutions of Sulfur in Carbon-Saturated Liquid Iron

A study has been made of the equilibria, at 1600° and 1800°C, between dilute solutions of sulfur in carbon-saturated liquid iron and gas mixtures consisting, initially, of argon and CS_2. By comparing the results obtained with those of previous workers on the corresponding H_2-H_2S-S in carbon-saturated liquid iron equilibria, the equilibrium sulfur pressures over these melts and the standard free energy of formation of gaseous CS have been obtained.

by C. J. B. Fincham and R. A. Bergman

THERMODYNAMIC properties of many high-temperature systems containing sulfur, such as slags, metal sulfides, and solutions of sulfur in liquid metals, have been studied by means of equilibration with known gas mixtures.[1-3] This method presupposes a complete and accurate knowledge of the thermodynamic data for all possible components of the gas phase at high temperatures. However, a survey of the data available up to 1952 on the thermodynamics of gaseous sulfur species and compounds, by Richardson and Jeffes,[4] showed that there was considerable uncertainty in the values of the free energies of formation of S, SO, HS, and CS. In many cases, this uncertainty made it impossible to decide whether or not these species would form a significant proportion of the sulfur present in the gas phase in any given system.

After the review by Richardson and Jeffes had been published, St. Pierre and Chipman[5] measured, by an indirect method, the free energy of formation of SO. This also enabled a clear choice to be made among the three possible spectroscopic values for the dissociation energy of S_2 into atoms,[6] thereby determining the free energy of formation of S from S_2, and fixing the free energy of formation of HS more accurately.[4]

The main purpose of the present investigation was to measure the free energy of formation of CS, which was still in considerable doubt. For example, at 1600°C, it could be estimated to be +6 ±25 kcal per mole,* most of the uncertainty being in the value of the dissociation energy.[6]

A secondary purpose of the investigation was to determine more accurately the equilibrium sulfur pressures over dilute solutions of sulfur in carbon-saturated liquid iron.

* Based on the dissociation energies of CS^0 and S_2,[6] the heat of sublimation of graphite,[6] and the assumption that the entropy of formation of CS is the same as that of CO.

General Method

Dilute solutions of sulfur in liquid iron, saturated with carbon, were brought to equilibrium at 1600° and 1800°C, with known gas mixtures consisting, initially, of A and CS_2. After equilibrium had been reached, the melts were quenched and analyzed for sulfur.

In the high temperature region of the furnace, an equilibrium was set up between the various possible sulfur species and compounds in the gas phase; namely, CS_2, CS, S_2, and S. (It can be calculated that the amounts of S_8 and S_6 are negligible at these temperatures.[6])

Morris and Buehl[7] and Kitchener, Bockris, and Liberman[8] had previously studied the corresponding

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system using gas mixtures consisting, initially, of H_2 and H_2S. At high temperatures, H_2, H_2S, HS, CS_2, CS, S_2, and S were present in the gas phase.

The equilibrium S_2 pressures in this system could not be calculated accurately because of the uncertainty in the free energy of formation of CS. For example, for H_2-H_2S-CS gas mixtures, in equilibrium with graphite and 1 atm of H_2 at 1600°C, the upper and lower uncertainty limits (quoted above) lead to ratios of p_{CS}/p_{H_2S} of 2.8×10^{-4} and 1.9×10^{-5}, respectively. These ratios give values of p_{S_2} of approximately 3×10^{-10} and 9×10^{-20} atm, respectively, for a gas mixture initially containing 5×10^{-4} atm of H_2S.

However, by comparing the results of the present investigation using A-CS_2 mixtures with those obtained using H_2-H_2S mixtures, the free energy of formation of CS can be evaluated much more accurately, and the equilibrium S_2 pressures in these systems determined. The details of the calculations are set out in a later section.

In performing these calculations only the results of Morris and Buehl were used, as the results of Kitchener, Bockris, and Liberman were considered to be less reliable for the following reasons:

1) The results of Kitchener, Bockris, and Liberman show considerable scatter, indicating some large experimental error. The reasons for this scatter are not obvious, but in the light of a later paper by Kitchener, Bockris, and Spratt,[9] and the experience of the present authors, it may have resulted from failure to reach carbon saturation in the time of the experiments.

2) The results of Morris and Buehl for carbon-free melts, obtained using the same techniques and apparatus as for the carbon-saturated melts, agree well with those of Sherman, Elvander, and Chipman.[4]

3) Morris and Buehl obtained results at several temperatures. Thus, the entropy of formation of CS could be obtained. Since it is likely to be close to that for CO, it would provide a check on the results. Kitchener, Bockris, and Liberman worked at only one temperature.

Experimental Methods

Gas Mixtures—A known flow rate of commercial argon (measured by a capillary flowmeter) was purified by passage over soda-lime and anhydrous magnesium perchlorate. Calculations based on the stability of COS[7] showed that the small amount of oxygen in the argon (<0.001 pct) would have a negligible effect on the results.

A small fraction of the argon was diverted from the main flow and passed through a bulb containing liquid carbon disulfide. The vapor pressure of CS_2 was held constant by immersion of the bulb in an ice-water bath. The amount of argon diverted could be controlled by a needle valve. The A-CS_2 mixture formed was combined with the main flow of argon, and the resulting mixture could either be made to flow to the reaction furnace or to the gas analysis system.

Reaction Furnace and Temperature Control—The furnace used, shown diagrammatically in Fig. 1, was a simple resistance furnace in which a graphite tube, ½ in. ID, 3 ft in length, served as both resistor and reaction tube.

The tube was a *slide-fit* through two drilled graphite blocks, which were bolted to the furnace end plates. This permitted the tube to slide freely during thermal expansion or contraction, but kept

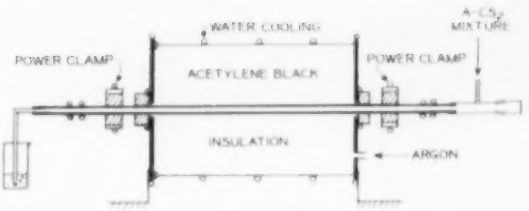

Fig. 1a—Diagram of graphite resistance furnace.

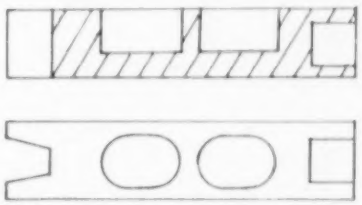

Fig. 1b—Diagram of graphite reaction boat.

entry of air into the furnace case to a minimum. The power connections were made by split graphite blocks clamped to each end of the furnace tube.

Loosely packed acetylene-black was used as insulation, and a stream of argon was flushed through the furnace case to prevent oxidation of the insulation and reaction tube. An extensive water-cooling system was used to prevent overheating of the furnace case and connections, and to facilitate quenching of the samples at one end of the furnace tube.

The graphite tubes used were slightly porous when new, and became somewhat more porous after use. However, analyses of the ingoing and outgoing gas mixtures, in the absence of a metal sample, showed that this porosity did not significantly affect the composition of the A-CS_2 mixtures if the argon pressure was kept equal on both sides of the tube. The experimental results for these tests are shown in Table I.

Power was supplied from a *step-down* transformer which was fed by a Variac autotransformer. Line voltage fluctuations were kept to a minimum by means of a constant voltage transformer on the input side of the Variac. With this system and manual adjustment of the Variac, the furnace temperature could be held steady within ±5°C at 1800°C. The maximum temperature in the furnace tube was constant to within ±5°C over a length of 4 in. at 1800°C (somewhat longer at lower temperatures).

The power requirements of the furnace were low, only about 1 kva being needed to maintain the temperature at 1800°C.

The temperature was measured by sighting a Leeds and Northrup disappearing-filament optical pyrometer through the end window, see Fig. 1a, onto the end of the reaction boat.

The system was calibrated by measuring the apparent melting temperatures of silver, iron, and platinum, which were held in alumina-lined graphite boats. No contamination of the samples by carbon was found.

The reaction boats used, shown in Fig. 1b, were shaped from pure graphite rod. Each boat had two cavities drilled into it, so that two samples could be used at one time.

Materials—Johnson, Matthey and Co. Ltd. spectrographically standardized pure iron was used. In some of the early experiments this pure iron was

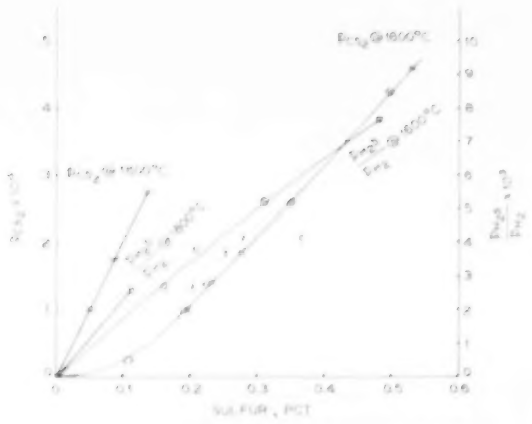

Fig. 2—Graph of ingoing partial pressure of CS_2 or ingoing ratio p_{CS_2}/p_{H_2} vs final percentage of sulfur (by weight) in carbon saturated liquid iron at 1600° and 1800°C.

used directly as the sample. However, it was found that the rate at which the iron reached saturation with graphite was relatively slow, especially in the presence of sulfur. This is in agreement with the results of Kitchener, Bockris, and Spratt.[9]

To avoid this difficulty two master alloys were prepared. One consisted of iron saturated with graphite, and was prepared by heating a mixture of pure iron and graphite powder in a graphite crucible at 1800°C for 2½ hr in an induction furnace. The other contained iron, carbon, and sulfur, and was prepared in a similar manner, but with the addition of chemically pure FeS. This alloy contained 0.98 pct S.

Table I. Tests on Porosity of Graphite Tubes

Test No.	Ingoing p_{CS_2}, Atm	Outgoing p_{CS_2}, Atm
1	1.96×10^{-3}	1.97×10^{-3}
2	1.73×10^{-3}	1.73×10^{-3}

Samples of any desired sulfur concentration could be made by blending appropriate amounts of the two master alloys. The sample weight usually used was about ½ g.

Procedure—The furnace was brought to the required temperature in a flowing atmosphere of argon. The A-CS_2 mixture was then started and given time to flush through the apparatus. The gas mixture was analyzed for CS_2 before and after each run, and the average of the two determinations was reported as the gas composition during the run. At no time was any significant difference found between the two analyses.

The reaction boat, containing two samples, was then inserted into the furnace. The samples were designed to have higher and lower sulfur concentrations than the expected equilibrium value, so that equilibrium was approached from both sides in each experiment. During the run temperature measurements were taken at frequent intervals, and any necessary adjustments made.

At the end of the experiment, the samples were pushed quickly into the water-cooled end of the furnace tube, where they were quenched very rapidly. Before chemical analysis, the carbon deposit on the surface of the sample was removed.

Methods of Analysis—The metal samples were analyzed for sulfur by the standard combustion method. The samples were heated to about 1270°C in a stream of oxygen, and the evolved SO_2 was absorbed in acidified water and titrated with a standard potassium iodate-iodide solution, using starch as the indicator. The method was standardized by use of U.S. Bureau of Standards analyzed steel samples having sulfur contents in the appropriate range. The accuracy of the method was about ±1 pct of the sulfur present for samples containing more than 0.1 pct S.

The A-CS_2 gas mixtures were analyzed for CS_2 by the xanthate method.[11, 12] The gas mixture was bubbled through a freshly prepared 5 pct KOH-ethyl alcohol solution, which absorbed the CS_2 with formation of a xanthate. This was then titrated against a standard iodine solution at a closely controlled pH value. At all flow rates used in these experiments, the CS_2 was completely absorbed in the first absorption bottle. The accuracy of the method was about ±4 pct.

Another method tried, but discarded because of lack of reproducibility of the results, was oxidation of the CS_2 by CuO at 500°C, and absorption and weighing of the CO_2 and SO_2 formed. Results obtained using this method agreed, within the experimental scatter, with those of the xanthate method.

Experimental Results

Preliminary Tests—A number of preliminary tests were carried out in order to find the time required to reach equilibrium and the effect of gas flow rate on the results.

It was found that the time required to reach equilibrium was of the order of several hours. It was therefore desirable to start with samples having sulfur contents close to the equilibrium values, and to approach equilibrium from both sides in each experiment. The times used are reported for each experiment in the table of results, Table II.

Table II. Experimental Results

Run No.	Temperature, °C	Ingoing $p_{CS_2}\times10^3$, Atm	Duration of Run, Min	Initial Pct S	Final Pct S
22	1600	2.095	290	0.98	0.364
				0.0	0.281
23	1600	1.85	120	0.35	0.282
				0.0	0.277
24	1600	1.85	80	0.35	0.282
				0.0	0.254
25	1600	1.40	140	0.35	0.232
				0.0	0.230
26	1600	1.38	90	0.35	0.219
				0.0	0.267
27	1600	1.06	175	0.25	0.192
				0.0	0.196
28	1600	1.06	100	0.25	0.198
				0.0	0.192
29	1600	4.56	240	0.55	0.530
				0.35	0.532
30	1600	4.25	115	0.50	0.492
				0.40	0.498
31	1600	2.58	165	0.40	0.346
				0.30	0.349
32	1600	0.25	165	0.20	0.106
				0.05	0.110
33	1800	0.99	90	0.160	0.0513
				0.075	0.0515
34	1800	1.756	75	0.160	0.0807
				0.075	0.0875
35	1800	2.76	75	0.160	0.1345
				0.075	0.1372

Variation of the gas flow rate between 9 and 17.4 cu cm per sec (measured at stp) caused no significant difference in the results obtained. This indicates that errors due to thermal diffusion or nonattainment of equilibrium within the gas were

negligible. A flow rate of 10 cu cm per sec at stp was used for all the final experiments.

Results—The final results obtained are listed in Table II. Fig. 2 shows a plot of p_{CS_2} in the ingoing gas* vs the final percentage by weight of sulfur in the metal at 1600° and 1800°C. The direction of the *arrow-heads* marking the individual points shows the direction (high or low sulfur) of approach to equilibrium. It should be noted that the point at 0.36 pct S, which deviates markedly from the line, started at a high sulfur level (0.98 pct) and did not have sufficient time to reach equilibrium. This also applies to some of the points which started at 0.0 pct S.

* All partial pressures quoted in this paper are measured in atmospheres.

The results of Morris and Buehl[7] for melts saturated with graphite are also shown in Fig. 2, and are plotted as p_{H_2S}/p_{H_2} in the ingoing gas (right hand scale) vs percentage of sulfur (by weight) in the metal at equilibrium. The values of p_{H_2S}/p_{H_2} had to be calculated from the *corrected* values reported by Morris and Buehl. This was done by the reverse of the calculation outlined in their paper, and by assuming that p_{H_2} was 1 atm. One of their results at 1600°C is omitted because it was carried out in an alumina crucible, and the final metal contained a high concentration of aluminum.

Table III. Thermodynamic Data Used

Reaction	Standard Free Energy Equation	Reference
$H_2 + \frac{1}{2} S_2 = H_2S$	$\Delta F^\circ = -21{,}580 + 11.81T$ cal	4
$\frac{1}{2} H_2 + \frac{1}{2} S_2 = HS$	$\Delta F^\circ = +8{,}000 + 0.0T$ cal	*
$\frac{1}{2} S_2 = S$	$\Delta F^\circ = +43{,}250 - 14.60T$ cal	5
$C + S_2 = CS_2$	$\Delta F^\circ = 3{,}100 - 1.73T$ cal	4

* Derived as in Ref. 4, but new value for the dissociation energy of S_2 (Ref. 5) was used.

Calculation of Results

In gas mixtures consisting, initially, of either A-CS_2 or H_2-H_2S, both CS_2 and H_2S will dissociate into various sulfur species and compounds at elevated temperatures. If the original partial pressures of CS_2 or H_2S in the gases before entering the hot zone, denoted by $p_{CS_2}(i)$ and $p_{H_2S}(i)$, are small compared with $p_A(i)$ or $p_{H_2}(i)$, the sulfur balance can be written in the form of a partial pressure balance, without introducing any significant error. Thus

$$p_{H_2S}(i) = p_{H_2S} + p_{HS} + 2p_{CS_2} + p_{CS} + 2p_{S_2} + p_S \quad [1]$$

and

$$2p_{CS_2}(i) = 2p_{CS_2} + p_{CS} + 2p_{S_2} + p_S \quad [2]$$

where symbols of the type p_{S_2} denote partial pressures at equilibrium.

If the two gas mixtures were in equilibrium with identical Fe-C-S alloys at a given temperature, they would also have been in equilibrium with one another. Hence, the partial pressures of S_2, S, CS_2, and CS would be the same in both gases.

On this basis, Eq. 2 may be subtracted from Eq. 1, giving

$$p_{H_2S}(i) - 2p_{CS_2}(i) = p_{H_2S} + p_{HS} \quad [3]$$

but

$$p_{H_2S} = K_1 \cdot p_{H_2} \cdot p_{S_2}^{1/2} \quad [4]$$

and

$$p_{HS} = K_2 \cdot p_{H_2}^{1/2} \cdot p_{S_2}^{1/2} \quad [5]$$

where K_1 and K_2 are the equilibrium constants for the reactions

$$H_2 + \tfrac{1}{2} S_2 = H_2S$$

and

$$\tfrac{1}{2} H_2 + \tfrac{1}{2} S_2 = HS$$

respectively.

Combining Eqs. 3, 4, and 5, and assuming that $p_{H_2} = 1$ atm

$$p_{S_2}^{1/2} = \frac{p_{H_2S}(i) - 2p_{CS_2}(i)}{K_1 + K_2} \quad [6]$$

Using Eq. 6, the value of p_{S_2} in equilibrium with a given Fe-C-S alloy at a given temperature can be calculated from the results of Morris and Buehl and the present investigation, and a knowledge of K_1 and K_2. Also

$$p_S = K_3 \cdot p_{S_2}^{1/2} \quad [7]$$

and

$$p_{CS_2} = K_4 \cdot p_{S_2}^{1/2} \quad [8]$$

where K_3 and K_4 are the equilibrium constants for the reactions $\frac{1}{2} S_2 = S$ and $C + S_2 = CS_2$, respectively, since the activity of carbon is unity in this system.

Combining Eqs. 2, 7, and 8 gives

$$p_{CS} = 2p_{CS_2}(i) - 2K_4 \cdot p_{S_2} - 2p_{S_2} - K_3 \cdot p_{S_2}^{1/2}$$

Since p_{S_2} is known from Eq. 6, the value of p_{CS} can be found, using known values of K_3 and K_4, but

$$p_{CS}/p_{S_2}^{1/2} = K_5$$

where K_5 is the equilibrium constant for the reaction

$$C_{(graphite)} + \tfrac{1}{2} S_2(g) = CS(g)$$

and, hence, the standard free energy of formation* of CS can be calculated.

* The standard states used in this paper are 1 atm pressure for gases and the pure solid for graphite.

From the data shown in Fig. 2, values of $p_{H_2S}(i)$ and $p_{CS_2}(i)$ were taken for six different sulfur concentrations in the metal at 1600°, and two at 1800°C. Using the thermodynamic data given in Table III to evaluate K_1, K_2, K_3, and K_4, and assuming that $p_{H_2} = 1$ atm in Morris and Buehl's experiments, the values of p_{S_2}, K_5, and the free energy of formation of CS were calculated for each case. A summary of the results is given in Table IV.

The values of K_5 and ΔF° are in good agreement with one another, except for those obtained from the 0.15 pct S point at 1600°C. This point was neg-

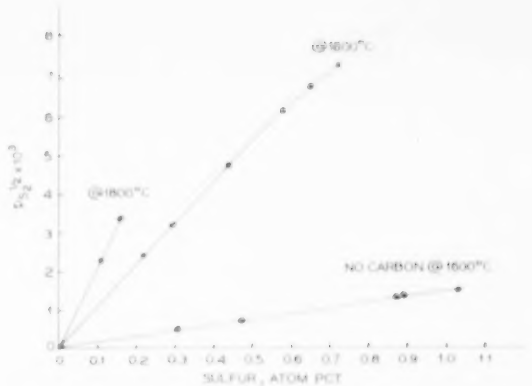

Fig. 3—Equilibrium sulfur pressures over carbon-saturated liquid iron-sulfur alloys at 1600° and 1800°C, and over carbon-free liquid iron-sulfur alloys at 1600°C, plotted as $p_{S_2}^{1/2}$ vs atomic pct sulfur in the iron.

lected in deriving the average ΔF° value, since measurements made at low sulfur concentrations, and hence low $p_{S_2}(1)$ values, are likely to be inaccurate. The average at 1800°C for ΔF° was weighted in favor of the 0.11 pct S point, as this was the only one experimentally measured by Morris and Buehl.

Free Energy of Formation of CS—An equation for ΔF° as a function of temperature can be derived from these results, and is found to be

$$C + \tfrac{1}{2}\,S_2 = CS \quad \Delta F^\circ_{1600^\circ-1800^\circ K} = +59{,}000 - 22.75T \text{ cal.}$$

In the authors' opinion (based on their estimates of the probable accuracies of their own measurements, those of Morris and Buehl, and the thermodynamic data used in the calculation, and how they affect the results), the uncertainty in this equation is ±7000 cal. These error limits would be considerably less if better data were available for the free energy of formation of HS.

Table IV. Summary of Calculations

Pct S in Metal	$p_{S_2}^{1/2}$ x 10⁶	p_{S_2} x 10¹²	K x 10⁻⁸	ΔF°, Cal: $C + \tfrac{1}{2}\,S_2 = CS$
At 1600°C				
0.15	2.48	6.03	0.756	18,180
0.20	3.31	1.16	1.50	15,600
0.30	5.00	2.97	1.58	15,940
0.40	6.60	5.15	1.95	16,940
0.45	7.30	7.20	0.99	17,170
0.50	7.94	8.28	1.91	17,100
			Average	16,556
At 1800°C				
0.075	1.75	1.53	6.54	11,260
0.11	2.58	2.25	5.13	12,260
			Average	12,900

Table V. Equilibrium Partial Pressures of Sulfur Compounds

Gas Species	Partial Pressure x 10⁶, Atm. at 1600°C	Partial Pressure x 10⁶, Atm. at 1800°C
H_2S	405.0	165.1
HS	54.5	47.7
CS_2	12.63	5.66
CS	6.45	17.18
S_2	2.19	1.12
S	6.52	14.28

A comparison of the free energy equation for CS with the corresponding one for CO,[9] viz., $\Delta F^\circ = -26{,}700 - 20.95T$ cal, shows that the entropy terms are very similar. Since this is what would be expected, it provides a check on the general method.

In order to show the relative importance of the different gaseous sulfur species and compounds at these temperatures, Table V lists their partial pressures in gas mixtures which would be in equilibrium with Fe-C-S alloys, saturated with carbon, containing 0.30 pct S at 1600° and 0.11 pct S at 1800°C, respectively.

The figures in Table V show that considerable errors (about 50 pct at 1600° and more than 100 pct at 1800°C) can be introduced if the equilibrium p_{S_2} value for a H_2-H_2S gas mixture (in equilibrium with graphite) is calculated on the assumption that only H_2, H_2S, and S_2 are present at high temperatures.

Solutions of Sulfur in Liquid Iron—Fig. 3 shows the equilibrium partial pressures of S_2 over carbon-saturated liquid iron-sulfur alloys at 1600° and 1800°C, and is plotted as $p_{S_2}^{1/2}$ vs atomic pct S in the metal (calculated using the carbon solubilities reported by Morris and Buehl). The values of p_{S_2} are those listed in Table IV. Also shown in Fig. 3 are the corresponding values of p_{S_2} for Fe-S alloys containing no carbon, at 1600°C. These were calculated from the results of Cordier and Chipman,[4] using the thermodynamic data for H_2S, HS, and S listed in Table III, and selecting only those runs in which no nickel was present. Sherman, Elvander, and Chipman[3] also studied the carbon-free system, but used sulfur concentrations higher than the range covered by Fig. 3.

At 1600°C, the activity coefficient of sulfur in dilute solutions in carbon-saturated iron is approximately seven times greater than it is in carbon-free iron. This is one of the reasons for the greater efficiency of desulfurization in the blast furnace, as compared with the open hearth furnace. Another reason is the much lower oxygen potential in the blast furnace.[10]

Summary

The standard free energy change for the reaction

$$C_{(graphite)} + \tfrac{1}{2}\,S_2(g) = CS(g)$$

has been measured at 1600° and 1800°C, by an indirect method. It can be represented as a function of temperature by the equation

$$\Delta F^\circ_{1600^\circ-1800^\circ K} = +59{,}000 - 22.75T\ (\pm 7{,}000)\ \text{cal}$$

a large part of the proposed error limits being due to uncertainty in the free energy of formation of HS.

The equilibrium S_2 pressures over dilute solutions of sulfur in carbon-saturated liquid iron have also been determined at 1600° and 1800°C. At 1600°C, the activity coefficient of sulfur in these melts is approximately seven times greater than that in the corresponding carbon-free Fe-S alloys.

Acknowledgments

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Effect of Oxygen Input Rates In the Decarburization of Chromium Steel

Methods for calculating the heat balance of a furnace during the oxygen blow and for estimating the concurrent change in chromium analysis have been developed. The carbon content at the end of the blow can be estimated by means of these relationships when the initial composition and temperature of the bath, the amount of oxygen injected, and the duration of the oxidizing period are known. The relationships are used to evaluate the effects of oxygen input rate, chromium content, and temperature of the bath before the blow on metallic oxidation, oxygen usage, and temperature at the end of the blow.

by G. W. Healy and D. C. Hilty

MAJOR considerations in the production of stainless steel are the utilization of stainless steel scrap and the recovery of chromium and other metallic values from the initial furnace charge. The decarburization of a bath of molten chromium steel with gaseous oxygen is usually accompanied by a considerable amount of metallic oxidation. Since recovery of this metal from the slag may require substantial expenditures of time and materials for slag reduction, holding metallic oxidation to the minimum consistent with good operating practice is generally desirable. The important role of temperature in minimizing metallic oxidation is illustrated by Fig. 1, taken from the results of Hilty, Healy, and Crafts,[1] who established the quantitative relations connecting the amounts of chromium, manganese, and iron oxidized during the oxidizing period of chromium steel heats with the composition of the initial charge and the temperature and composition of the molten bath after oxidation. Higher temperatures after the oxygen blow result in lower metallic oxidation.

Although high temperatures are desirable for minimizing metallic oxidation, practical operating considerations limit the degree to which they can be employed. Excessively high temperatures or prolonged operation at moderately high temperatures may cause serious damage to the furnace refractories, so that a compromise must be effected. The problem, therefore, is one of controlling the oxidizing period of chromium steel heats to the shortest time at the highest practical temperature.

The most effective tool the steel melter has for attaining high temperature while decarburizing a chromium steel heat is now commonly considered to be the oxygen lance with an adequate supply of gaseous oxygen. In order for the tool to be effective, however, the heat resulting from the oxidation of carbon, chromium, silicon, manganese, and iron in the bath must exceed the heat losses from the furnace. General recognition of this principle has stimulated a trend toward faster injection of oxygen. For example, Pachaly[2] proposed a high temperature at the start of the oxygen blow or a high rate of oxygen input as a means of obtaining the desired carbon level with high chromium recovery.

On the other hand, limited understanding of the specific effects of oxygen input rate has hampered development of optimum practices. As part of a broad study of the metallurgy of chromium steel melting, therefore, the Linde Air Products Co. and the Electro Metallurgical Co. at their Metals Research Laboratories have evaluated the heat-balance during the oxidizing period in terms of oxygen input rate. The evaluation has then been related to factors such as temperature increase, metallic oxidation, oxygen utilization, etc., and extrapolated to include a wide

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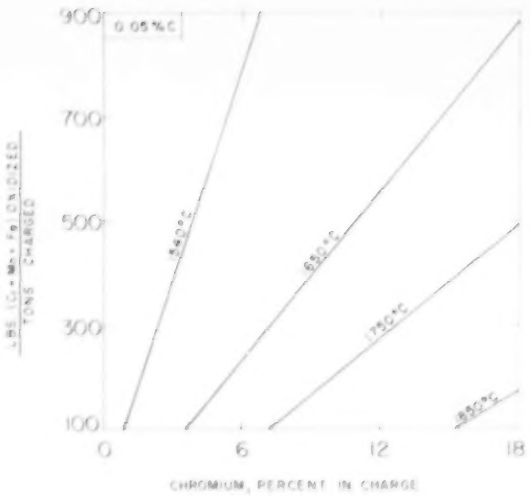

Fig. 1—Effect of temperature on metallic oxidation in blowing chromium steel heats with oxygen to 0.05 pct C.

range of furnace sizes. The results are believed to furnish a basis for the design of economical practices and, although more accurate data are needed, to indicate the means for more readily controlling the process.

Distribution of Energy

In any process of this type, temperature changes depend on the distribution of energy. During the oxygen blow in a stainless steel heat, the source of energy is the heat of oxidation of the bath, which is directly related to the quantity of oxygen employed since, in general, power is off during the oxygen blow. Consequently, the energy distribution required to bring about a given temperature increase in the bath can be represented schematically in terms of the amount of oxygen as a function of the time during which the temperature increase is developed, as shown in Fig. 2. Because of the heat losses, the total energy input, i.e., oxygen, increases as the time taken for injection of the oxygen increases.

The basis of Fig. 2 is that the energy input, Qi, is distributed three ways: increase in sensible heat of the bath, Qb; increase in sensible heat of the refractories, Qr; and external heat losses, Qx. The heat balance equation, therefore, may be written

$$Qi = Qb + Qr + Qx. \qquad [1]$$

Evaluation of the heat balance depends upon expressing this energy distribution in terms of measurable quantities.

Heat of Oxidation

Item Qi of Eq. 1 is the heat of oxidation of the bath plus any electrical energy supplied during the oxidizing period. The heat of oxidation depends upon the compositions and amounts of the oxides formed. In the usual stainless steel heat the metallic elements oxidized during the oxygen blow are iron, chromium, and manganese. Since manganese in the concentrations normally present up to about 1 pct may be assumed equivalent to chromium,[1] the metal oxides of interest are those of iron and chromium. Recent work by Hilty, Forgeng, and Folkman[2] demonstrated that the oxide phases in equilibrium with molten Fe-Cr alloys are, in order of increasing chromium concentration, FeO-rich liquid, chromite, *distorted spinel*, and Cr_2O_3. Data for calculating the heat of reaction of oxygen with the molten bath to form each of these oxides are available except in the case of *distorted spinel*. The heat of formation of *distorted spinel*, however, very likely is between those of Cr_2O_3 and $FeCr_2O_4$ (chromite). Since the heat of formation of Cr_2O_3 recently estimated by Chipman[3] differs from that of $FeCr_2O_4$ by only a small amount, *distorted spinel* formation can probably be ignored without introducing serious error in estimates of the heat of metallic oxidation. For the present purpose, therefore, the metal oxides involved are considered to be liquid FeO, solid $FeCr_2O_4$, and solid Cr_2O_3.

Carbon is presumed to be oxidized to CO_2. The heat of oxidation of carbon, however, is calculated on the assumption that CO formed as a primary product is oxidized by air to CO_2 before escaping from the furnace.

The heat evolved per unit volume of oxygen in the formation of each of these oxides from the molten bath with high purity oxygen and with air, referred to standard conditions of metering, is tabulated in Table I. For convenience in subsequent correlation with heat losses and electrical power inputs, this heat is expressed in terms of kilowatt-hours. The heat of reaction and the enthalpy data employed in the derivation of Table I are listed in Tables II and III.

Table I. Heats of Oxidation Per Cubic Foot Oxygen

Oxide Formed	Kw-Hr per Cu Ft O_2, Metered at 70°F, 1 Atm	
	As Elemental Oxygen	As Air
FeO	0.142	0.079
$FeCr_2O_4$	0.217	0.154
Cr_2O_3	0.225	0.162
CO_2	0.182*	

* Energy per cubic foot of elemental oxygen required for first stage of oxidation to CO. Oxidation to CO_2 due to reaction with infiltrated air. Elemental oxygen usage is 16.1 cu ft per lb C.

The heat of carbon oxidation may be calculated directly by means of the data of Table I. For estimation of the heat of metallic oxidation, however, the data of Table I must be related to the chromium content of the bath after oxidation. This relation is shown in Fig. 3.

In the derivation of Fig. 3, the slags formed during oxidation of the bath were considered to be mixtures of FeO and $FeCr_2O_4$ or $FeCr_2O_4$ and Cr_2O_3, depending on the chromium concentration. Previous work[4] has

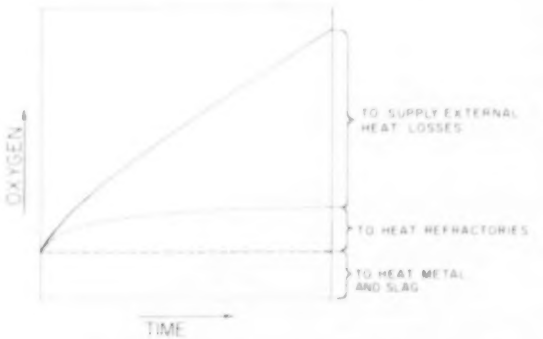

Fig. 2—Effect of time on the amount of oxygen required for a prescribed temperature increase.

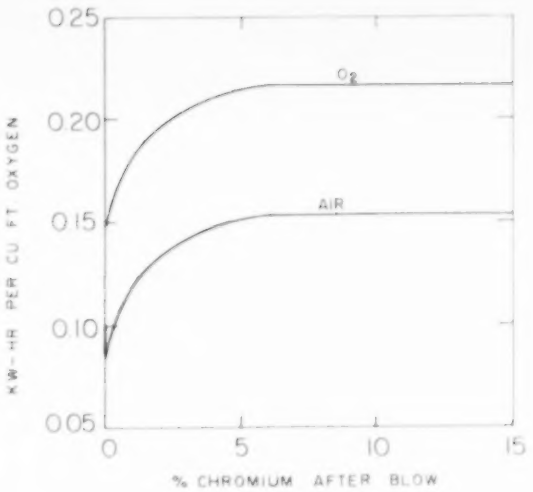

Fig. 3—Heat of oxidation of metallics in bath.

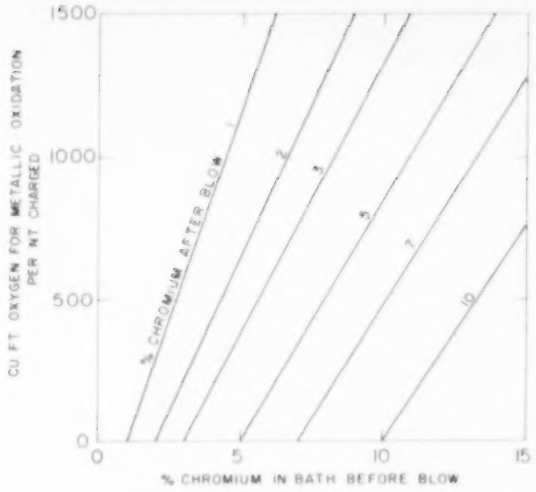

Fig. 4—Estimation of chromium content of bath after oxygen blow.

shown that the Cr:Fe ratio of slags at the end of the oxidizing period of stainless steel heats is empirically related to metal composition according to the equation

$$\log\left(\frac{\%\ \text{Cr} + \%\ \text{Mn}}{\%\ \text{Fe}}\right)\text{in slag} = 0.812 \log\left[\frac{\%\ \text{Cr} + \%\ \text{Mn}}{\%\ \text{Fe}}\right]\text{in metal} + 1.238. \quad [2]$$

With the help of Eq. 2, assuming manganese to be equivalent to chromium, it is possible to calculate the ratio of FeO to $FeCr_2O_4$ or $FeCr_2O_4$ to Cr_2O_3 corresponding to any metal composition and, consequently, the fraction of the total oxygen combined in each of these oxides. For example, if the metal at the end of the oxygen blow contains 4.5 pct Cr, the balance mainly iron, Eq. 2 indicates that a Cr:Fe ratio of 1.45 can be expected in the slag. A slag containing $FeCr_2O_4$ and FeO in the molecular ratio of 3.515 to 1 has this chromium to iron ratio, and in it 93.35 pct of the oxygen is combined as $FeCr_2O_4$, while 6.65 pct is in FeO. Taking 93.35 pct of the heat of oxidation for $FeCr_2O_4$ and 6.65 pct of that for FeO, given in Table I, results in a heat of oxidation of 0.212 kw-hr per cu ft O_2 corresponding to 4.5 pct Cr. This and similar calculations were employed to establish the upper curve of Fig. 3. For all practical purposes, the heat of oxidation may be considered constant and equal to 0.22 kw-hr per cu ft O_2 above about 6 pct Cr. The lower curve, labelled *air*, shows the decreased heat effect when air is the oxidizing agent.

Table II. Heats of Reaction at 1600°C

Reaction		ΔH, Cal per Mol	Reference
Cr_2O_3 (s)			
$2\,Cr + 4\,O$	$= Cr_2O_3$ (s)	−244800	4
$2\,O_2$	$= 4\,O$	−111720	5
$2\,O_2 + 3\,Cr$	$= Cr_2O_3$ (s)	−356520	
Chromite (s)			
$2\,Cr$ (l) $+ 3/2\,O_2$	$= Cr_2O_3$ (s)	−279000	6
Fe (l) $+ 1/2\,O_2$	$= FeO$ (l)	− 58500	6
$2\,Cr$	$= 2\,Cr$ (l)	0	5
FeO (l) $+ Cr_2O_3$ (s)	$= FeCr_2O_4$ (s)	− 6160	7-9
$2\,Cr + Fe$ (l) $+ 2\,O_2$	$= FeCr_2O_4$ (s)	−343660	
FeO (l)			
Fe (l) $+ 1/2\,O_2$	$= FeO$ (l)	−58500	6
Carbon			
$C + O$	$= CO$	−3510	5
$1/2\,O_2$	$= O$	−27930	5
$CO + 1/2\,O_2$	$= CO_2$	−66560	5
$C + O_2$	$= CO_2$	−103900	

The heat of oxidation of the bath can now be calculated if the amount of carbon oxidized, the volume of oxygen consumed, and the equivalent chromium content of the bath after oxidation are known. Of these factors, only the first two are subject to direct control. The amount of carbon oxidized is fixed by the carbon content of the charge before oxidation and the final carbon specification for the heat. The quantity of oxygen used can be regulated at will. For purposes of prediction, therefore, estimation of the chromium content of the bath after oxidation from knowledge of the more independent variables is desirable.

The quantity of chromium remaining in the bath after oxidation is equal to the quantity of chromium in the charge before oxidation less the amount oxidized, neglecting minor losses by splashing or volatilization. Moreover, the volume of oxygen used for metallic oxidation is directly proportional to the weight of metal oxidized. Hilty, Healy, and Crafts developed the following equation for calculating the quantity of metal oxidized.

$$W = 2000\,(\text{Cr}_i - \text{Cr}_f)/([100\,S/(1+S)] - \text{Cr}_f) \quad [3]$$

where W equals lb metal oxidized per net ton of charge; Cr_i (% Cr + % Mn) in the charge before oxidation; Cr_f (% Cr + % Mn) in the bath after oxidation; and S, (% Cr + % Mn) per % Fe in the slag after oxidation.

Table III. Enthalpy at 1600°C

Item		$H_{1600°C} - H_{25°C}$, Cal per Mol	Reference
Oxygen			
	O_2	13020	8
Air			
	O_2	13020	8
	$3.76\,N_2$	46410	8
	4.76 Air	59430	

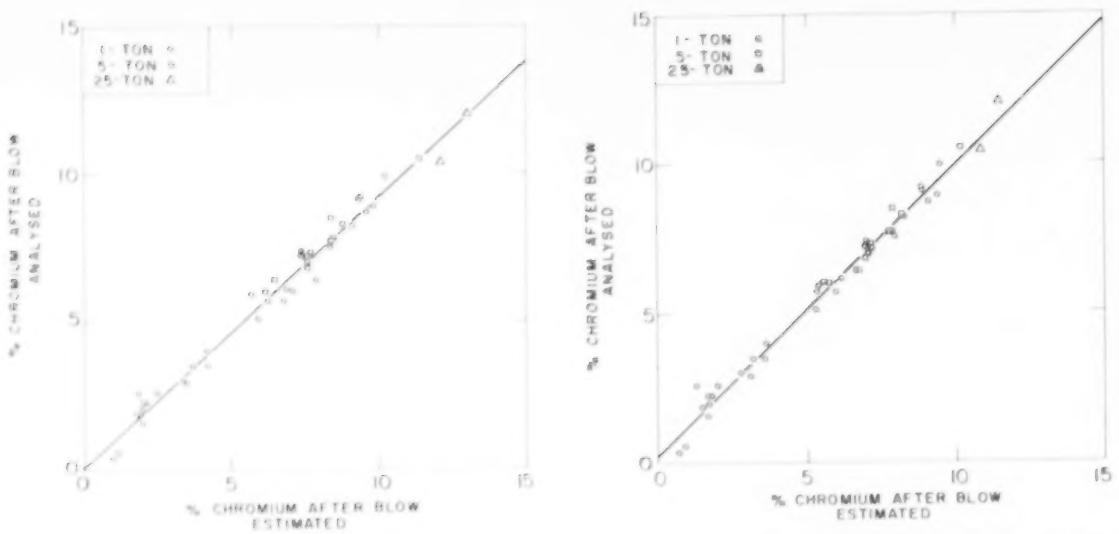

Fig. 5—Comparison between estimated and observed chromium content after blow: a) LEFT, neglecting oxidation by air; and b) RIGHT, correcting for oxidation by air.

This equation was derived on the assumption that no slag was present before the oxygen blow. However, the nominal amounts of slag normally used during meltdown will not seriously affect its validity. Assuming the constitution of the slag to be as discussed above, simple stoichiometric calculation leads to the following equations, whose derivation is shown in Appendix I: more than 6 pct Cr in bath after oxidation

$$Cr_f = Cr_i + Y[100S - Cr_i(1 + S)]/(9916S + 9236) \quad [4]$$

less than 6 pct Cr in bath after oxidation

$$Cr_f = Cr_i + Y[100S - Cr_i(1 + S)]/(11154S + 6924) \quad [5]$$

where Y = cu ft O_2 used for metallic oxidation per ton of charge. With the aid of Eq. 2 for the evaluation of S, Eqs. 4 and 5 may be plotted to give a family of straight line curves, as shown in Fig. 4. This chart permits estimation of the chromium content of the bath after oxidation as a function of oxygen usage and chromium content of the charge before oxidation—two *independent* variables.

To test the reliability of Fig. 4, the percentage of chromium after the blow was estimated from this figure for the arc furnace heats listed in Tables IV and V. The estimated chromium contents are compared to the actual analyses in Fig. 5a. The correlation is quite good, but there is a definite trend toward overestimation of chromium percentage after the blow. This suggests that more oxidation occurred than is accounted for by the oxygen used. It might at first be suspected that the trend could be due to the presence of oxides different from those postulated. It is substantially the same, however, if Fig. 4 is recalculated to conform to an assumption that the oxides are FeO and Cr_2O_3.

The amounts of oxygen that would result in the changes in composition shown in Tables IV and V were then determined from Fig. 4, and the excess of oxygen over that actually injected was calculated. Although variations from heat to heat were quite wide, there was a clear indication that the longer the duration of the heat, the greater this apparent excess of oxygen, an observation suggesting that atmospheric oxidation might account for the trend noted in Fig. 5a. Consequently, the rates of oxygen input due to an infiltration of air that would result in this excess oxygen were calculated for the heats listed in Tables IV and V with the following average results for the different sizes of furnaces: 1-ton heats, 11.5 cu ft O_2 per ton per min; 5-ton heats, 5.0 cu ft O_2 per ton per min; and 25-ton heats, 3.2 cu ft O_2 per ton per min.

These oxidation rates are shown graphically in Fig. 6 and appear to have a reasonable trend with furnace size. Applying these correction factors, and reestimating chromium after the blow, the results shown in Fig. 5b are obtained. It can be seen that the trend toward overestimation of residual chromium has disappeared.

If oxidation due to infiltration of air is occurring, then this additional heat of oxidation must be included in the heat input. The lower curve of Fig. 3 shows the resultant heat effect. The total heat of oxidation, therefore, is the sum of the heats of oxidation of carbon and metallics oxidized by injected oxygen and the heat of oxidation of the bath resulting from air infiltration. All of these quantities can be readily estimated by means of Table I and Figs. 3, 4, and 6. For evaluation of the total heat input during the oxidizing period, it is only necessary to add any electrical energy that may have been supplied to the furnace during this period.

Increase in Sensible Heat

Returning to the heat balance, Eq. 1, the portion of the equation denoting increase in sensible heat during the oxidizing period, $Qb + Qr$, can be expressed as the product of *apparent* heat capacity of the furnace and bath, C_p', and the change in temperature, ΔT; that is

$$Qb + Qr = C_p'\Delta T. \quad [6]$$

An attempt was made to determine experimentally the apparent heat capacity of a 1-ton experimental furnace by a series of tests in which immer-

sion thermocouple readings were taken at measured intervals of time, during which measured increments of electrical energy were added. A discussion of this effort and its results is given in Appendix II. The figure of 0.35 kw-hr per °C, almost double the theoretical one of 0.19 kw-hr per °C per ton steel, indicated that the effect of the furnace lining on the apparent heat capacity was unexpectedly great with this size furnace.

A mathematical analysis of the problem was then made, as set forth in the Appendix, with the result shown in Fig. 7. It is seen that the apparent heat capacity, which is the quantity measured by such experiments as were described, is made up of three items: a constant figure representing the true heat capacity of the charge; an item that increases rapidly at first, and then more slowly, due to absorption of heat by the furnace lining; and a third one that takes into account the change in the external heat loss rate with changing temperature. From Fig. 7, the apparent heat capacity for the 1-ton furnace for 6 min is found to be 0.31 kw-hr per °C; this is in agreement with the empirically determined value of 0.35 kw-hr per °C for the same average time.

The influence of furnace size on apparent heat capacity was calculated as described in Appendix II. As the furnace size increases, the proportion of heat absorbed by the refractories decreases, so that the apparent heat capacity approaches the true heat capacity of the molten bath more closely. The results of these calculations are shown in Fig. 8.

External Heat Loss

The only remaining item of the heat balance equation to be evaluated is the external heat loss, Q_e. Since the change in the external heat loss with temperature has been included in the derivation of the apparent heat capacity as described in the Appendix, the external heat loss can be expressed as the product of the heat loss rate at the initial temperature, q_e, and time, t, as follows:

$$Q_e = q_e t. \qquad [7]$$

In the case of the 1-ton experimental furnace several estimates have been made of q_e. The multiple correlation mentioned above in connection with the apparent heat capacity leads to a value of 300 kw. During these tests, however, infiltration of air must have been occurring, oxidizing the bath and supplying additional energy. The energy input rate from this source would have been 104 kw. Therefore the true heat loss rate estimated in this manner would be 404 kw.

In Appendix II the heat loss rate calculated from furnace dimensions and materials is 330 kw. The difference between this and the first estimate may be due to underestimation of heat transfer by radiation and conduction, as well as to neglect of heat carried out by air sweeping over the bath.

Finally, an average value of heat loss rate of 400 kw can be calculated from the data given in Table IV. For this calculation an average temperature increase must be estimated. Such estimation can be done with the help of Fig. 9, a recent revision[10] of Hilty's original chromium-carbon-temperature relationship,[11] using average values of chromium and carbon before and after the blow. This method is open to some criticism when applied to conditions before the blow, since Fig. 9 can only properly be employed if the bath is thoroughly oxidized. Unfortunately, immersion thermocouple readings were

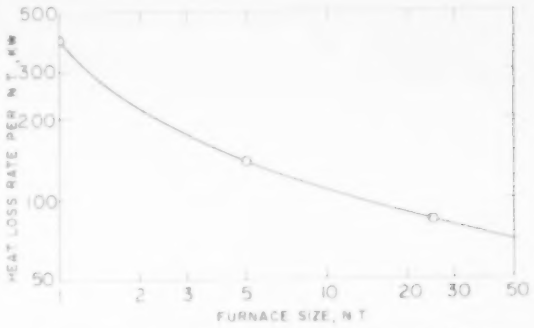

Fig. 6—Effect of furnace size on approximate air infiltration rate.

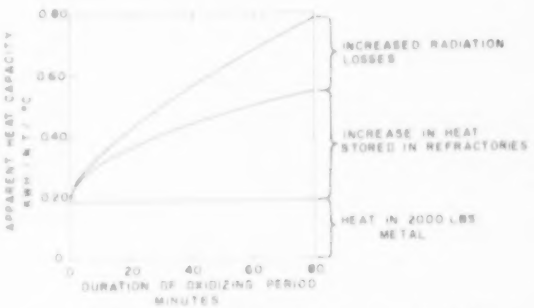

Fig. 7—Factors affecting apparent heat capacity of 1-ton experimental furnace.

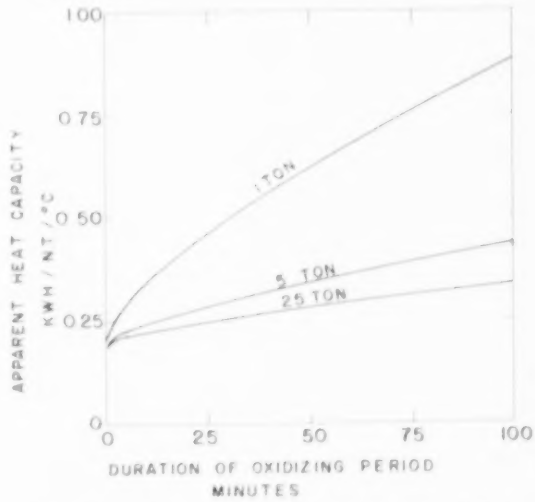

Fig. 8—Effect of time and furnace size on apparent heat capacity.

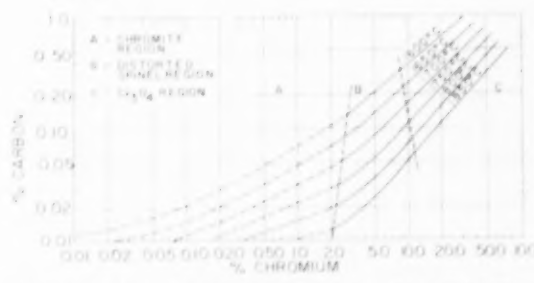

Fig. 9—Relationship between chromium, carbon, and temperature in oxidizing steel baths.

Table IV. Data for Oxidizing Period of 1-Ton Heats

Heat No.	Charge Wt, NT	Before Blow		After Blow		Oxygen, Cu Ft	Oxygen Input Rate, Cu Ft per Hr	Elapsed* Time, Min	Power Input, Kw-Hr
		Pct (Cr + Mn)	Pct C	Pct (Cr + Mn)	Pct C				
1	0.87	8.1	0.34	0.4	0.010	1860	3000	44	—
2	0.87	8.7	0.34	0.6	0.014	1850	3000	46	—
3	0.89	9.8	0.27	5.7	0.030	486	3500	10.5	8
4	0.89	8.4	0.35	5.7	0.035	438	3500	8.5	8
5	0.90	8.1	0.25	6.0	0.045	219	3500	19	117
6	0.89	8.9	0.29	6.1	0.040	350	3500	9	33
7	0.88	8.9	0.11	5.1	0.045	320	3500	7	—
8	0.89	7.8	0.10	5.7	0.042	233	3500	4	—
9	0.89	9.1	0.25	7.2	0.049	292	3500	6	8
10	1.01	11.6	0.28	6.4	0.024	661	5000	17	25
11	1.03	10.2	0.41	7.5	0.036	416	5000	6	8
12	1.05	11.8	0.29	9.9	0.073	332	5000	9	42
13	1.04	11.0	0.31	9.2	0.048	332	5000	7.5	29
14	1.04	10.7	0.26	8.2	0.048	332	5000	9	42
15	1.04	11.2	0.25	8.7	0.032	332	5000	6	17
16	1.04	10.9	0.26	9.1	0.042	332	5000	6	17
17	1.04	11.5	0.26	8.9	0.062	332	5000	6	17
18	1.01	7.4	0.23	3.5	0.016	644	5000	10	17
19	1.01	7.5	0.21	4.0	0.020	650	5000	9	8
20	1.01	7.2	0.39	2.9	0.015	795	5000	10	8
21	1.00	7.7	0.35	3.5	0.022	839	5000	12	17
22	0.99	5.4	0.30	1.6	0.016	747	5000	10	4
23	0.95	7.3	0.33	3.0	0.017	782	5000	13	25
24	0.88	6.2	0.42	2.0	0.020	916	5000	13	8
25	0.84	5.8	0.27	1.9	0.026	833	5000	12	17
26	0.83	5.9	0.20	2.3	0.022	750	5000	12	25
27	0.82	5.8	0.07	2.3	0.015	666	5000	9	8
28	0.78	5.5	0.18	2.6	0.019	708	5000	14	37
29	0.82	6.8	0.21	2.6	0.013	771	5000	12.5	33
30	0.89	9.2	0.44	7.4	0.085	360	11000	4.0	—
31	0.89	8.7	0.34	5.9	0.031	530	15000	4.0	—

* Total time between both samples before and after blow.

Table V. Data for Oxidizing Period of 5 and 25-Ton Heats

Group No.	Charge Wt, NT	Before Blow		After Blow		Oxygen, Cu Ft	Elapsed* Time, Min	Power Input, Kw-Hr
		Pct (Cr + Mn)	Pct C	Pct (Cr + Mn)	Pct C			
1	4.73	10.9	0.34	8.3	0.054	1960	19.2	—
2	4.74	11.0	0.31	7.7	0.042	2270	21.1	—
3	4.71	10.8	0.31	7.8	0.046	2060	19.2	—
4	4.57	9.3	0.29	6.8	0.038	1580	17.5	26
5	4.60	9.3	0.32	7.0	0.047	1580	17.3	—
6	4.60	9.2	0.29	7.0	0.059	1480	15.2	—
7	4.60	9.2	0.31	7.2	0.049	1540	15.3	—
8	4.54	9.2	0.30	7.3	0.055	1450	14.5	30
9	4.58	9.9	0.41	8.5	0.092	1540	15.0	7
10	4.60	10.4	0.42	8.3	0.059	1650	16.3	—
11	4.40	7.6	0.29	6.4	0.072	1105	12.2	—
12	4.45	7.5	0.25	6.0	0.049	1210	12.3	18
13	4.97	14.8	0.91	10.5	0.043	3900	34.5	6
14	23.00	15.6	0.57	10.4	0.030	16000	59.0	—
15	20.40	16.5	0.92	12.0	0.069	22500	71.0	—

* Total time between both samples before and after blow.

available for only a few of the heats, so this has been the only method available for estimating initial temperatures in most cases. Furthermore, Fig. 9 itself may be somewhat in error, as it is admittedly a tentative representation pending the completion of further experimental work. All things considered, however, the use of a heat loss rate that satisfies the average conditions encountered—400 kw in this case—seems the most practical choice, since it will automatically tend to minimize systematic errors in the assumptions. Moreover, it permits the same treatment to be applied to all the data presented, including the 5 and 25-ton heats listed in Table V. For these, a direct calculation of heat loss rate was impossible as information on dimensions was not available. For estimates of the heat loss rates, see Fig. 10.

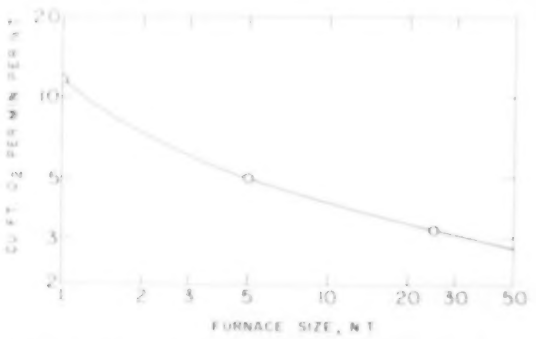

Fig. 10—Effect of furnace size on approximate heat loss rate.

Test of Heat Balance Calculations

By letting ΔH_c denote the heat of oxidation of carbon, ΔH_m represent the heat of metallic oxidation, and E designate any electrical energy added during the oxidizing period of the heat, the heat balance equation can now be rewritten as follows:

$$\Delta H_c + \Delta H_m + E = C_p' \Delta T + q_r t. \qquad [8]$$

By means of Eq. 8 and the evaluations of ΔH_c, ΔH_m, C_p', and q_r that have been described, the composition of the metal after an oxygen blow can be predicted if the analysis of the charge before the blow, the starting temperature, the amount of oxy-

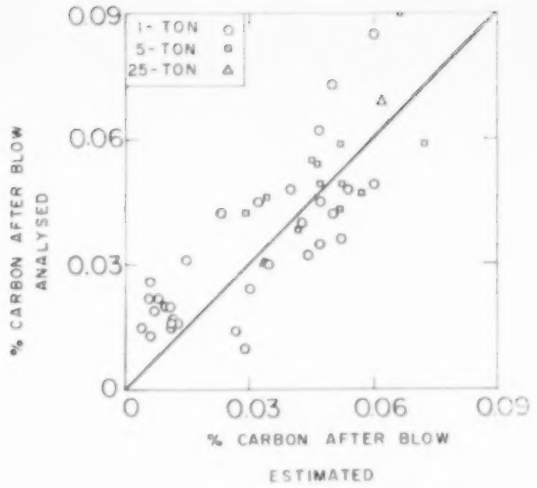

Fig. 11—Comparison of estimated and analyzed carbon contents after blow.

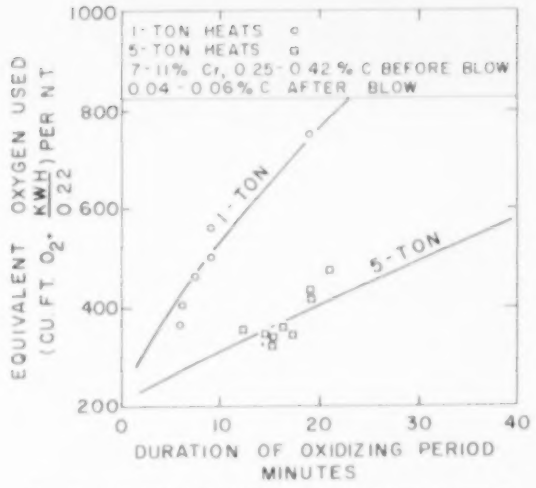

Fig. 12—Correlation of calculated effect of time on oxygen consumption (curves) with experimental observations (data points).

gen injected, the amount of electrical energy used, and the duration of the oxidizing period are known. This prediction involves trial and error solution of the equation according to the following steps:

1) Estimate amount of atmospheric oxidation from Fig. 6 and the elapsed time. Adding this atmospheric oxygen to the elemental oxygen that was injected gives the total oxygen added to the system.

2) From the initial carbon content and the specified final carbon content, the weight of carbon to be oxidized may be calculated, along with the oxygen required.

3) Deducting the oxygen needed for carbon removal from the total amount added yields the amount available for metallic oxidation. It is now possible to read from Fig. 4 the chromium content after the blow.

4) The heat of oxidation is then calculated, including the increments derived from oxidation of carbon and of metallics. Electric energy is added, if any was used, to obtain the total input. The heat

Table VI. Uncertainty in Calculations

Item	Uncertainty	Resultant Uncertainty in Pct C after Blow
Temperature before blow	±25°C	0.007
Pct C before blow (sampling, etc.)	±0.05	0.001
Pct Cr before blow (sampling, etc.)	±0.20	0.001
Oxygen usage	±5 pct = 17 cu ft	0.004
Time	½ min*	0.003
Electric energy	4 kw-hr†	0.004
Pct C after blow (sampling, etc.)	±0.005	0.005

* Log sheets show time in even minutes.
† Average input rate 500 kw, time from log sheets in even minutes.

loss, based on Fig. 10 and the elapsed time, is deducted.

5) Sensible heat from item 4 and heat capacity from Fig. 8 yield the temperature increase. The initial temperature may be measured by immersion thermocouple or, if the bath is boiling, estimated from Fig. 9. Adding the calculated temperature increase gives the final temperature which, together with the final chromium content estimated in step

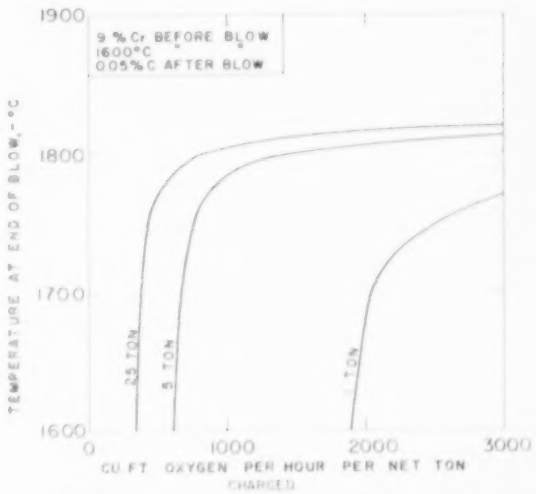

Fig. 13—Effect of blowing rate and furnace size on temperature attained when bath is blown to 0.05 pct C.

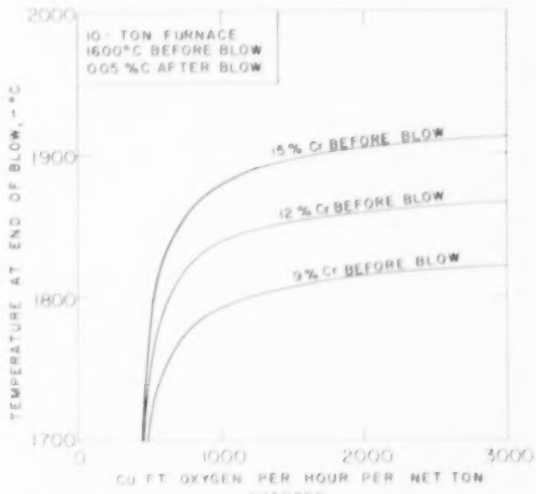

Fig. 14—Effect of blowing rate and initial chromium content on temperature attained when bath is blown to 0.05 pct C.

3, permits final carbon to be read from Fig. 9. If the final carbon content found in this way differs significantly from that specified in step 2, it may be necessary to repeat the calculations from that point on until reasonable agreement is obtained.

A specific example may show more clearly how this estimate of final composition would be achieved. Consider Heat No. 15 of Table IV. Data for this example are: percentage of chromium plus percentage of manganese before blow, 11.2; percentage of carbon, 0.25; oxygen used, 332 cu ft; charge weight, 1.04 net tons; total time between test before blow and end of blow, 6 min; and power used between test before blow and end of blow, 17 kw-hr.

1) Estimate of total oxygen:
   Pure oxygen — 332 cu ft
   Oxygen from air 6 min x 11.5 cfm — 69 cu ft
   Total — 401 cu ft.
2) Carbon oxidized:
   Carbon in bath — 0.25 pct
   Aim — 0.05 pct
   Oxidized — 0.20 pct
   0.20 pct x 1.04 *NT* x 2000 lb per *NT* = 4.17 lb oxidized
   Oxygen for carbon 4.17 x 16.1 = 67 cu ft.
3) Chromium content after blow:
   Oxygen reacted — 401 cu ft
   Oxygen for carbon — 67 cu ft
   Oxygen for metallics — 334 cu ft
   Oxygen for metallics, per *NT* 334/1.04 = 321 cu ft
   Entering Fig. 4 at 11.2 pct Cr and 321 cu ft, the result obtained is: Cr after blow = 9 pct (analysis showed 8.7 pct).
4) Heat of oxidation and heat losses:
   (Data from Fig. 3, for 9.0 pct Cr after blow)
   Oxygen reacting with carbon
   67 x 0.18 = 12.1 kw-hr
   Oxygen reacting with metallics
   265 x 0.22 = 58.3 kw-hr
   Oxygen from air reacting with metallics
   69 x 0.15 = 10.4 kw-hr
   Total heat of oxidation — 80.8 kw-hr
   Electric energy — 17.0 kw-hr
   Total energy input — 97.8 kw-hr
   Heat losses—6 min x 6.67 kw-hr per min — 40.0 kw-hr
   Heat available for temperature increase — 57.8 kw-hr.
5) Estimated final temperature:
   Temperature at start, from Fig. 9 for 11.2 pct Cr and 0.25 pct C — 1670°C
   Temperature increase: 57.8 kw-hr ÷ 0.30 kw-hr per °C (from Fig. 8, for 6 min) — 193°C
   Estimated final temperature — 1863°C.
6) Estimated analysis:
   From Fig. 9, at 9 pct estimated chromium and 1863°C, 0.044 pct C is obtained.
   Recalculation using 0.044 pct C as the carbon specified in step 2 checks out at 0.044 pct C predicted (analysis showed 0.032 pct).

Comparing the results of such predictions of bath composition at the end of the oxidizing period with compositions actually observed offers a means of testing the heat balance calculations. Consequently, predictions of the carbon content after the oxygen blow were made for each of the heats in Tables IV and V by the procedure just outlined. In Fig. 11 these estimated carbon contents are compared with those actually observed.

A considerable amount of scatter, which may be disturbing at first sight, is apparent in Fig. 11. If, however, the cumulative effect of uncertainties in the several quantities measured is considered, a good deal of the scatter is readily explained. Table VI shows the probable limits of accuracy of several items of data used in the calculation, and their end effect when carried through the calculation for Heat No. 15 in the example above.

Among these errors, the effects of temperature before the blow, the analytical errors, and the effect of percentage errors in oxygen volume are substantially the same for large furnaces. The cumulative effect of these uncertainties on the carbon content of the bath at the end of the oxidizing period is ±0.011 pct C if they are randomly distributed and ±0.025 pct C if they are all in the same direction.

Several additional sources of error have not been considered in this tabulation. The heat loss rate and the air infiltration rate may well be affected to a considerable extent by slag viscosity, and by the manipulation of the oxygen lance. There is some indication that heat loss rates tend to be higher for the heats finishing below 3 pct Cr. In these, a fluid high-iron slag is encountered, while for heats finishing at higher chromium contents the slag is viscous or lumpy, and frequently appears cold except in the immediate vicinity of the lance. A fluid slag could be expected to transfer heat more rapidly out

Table VII. Decarburization Conditions

Oxygen Input Rate, Cu Ft per Hr per *NT* Charged	Time Required, Min	Oxygen Required, Cu Ft per *NT* Charged	Fe + Cr + Mn Oxidized, Lb per *NT* Charged	Temperature Attained, °C	Chromium Content of Bath after Blow, Pct
Example I*					
1000	22	370	76	1800	6.7
2000	8	275	43	1820	7.7
Example II†					
1000	34	565	115	1880	11.2
2000	13	430	68	1900	12.9

* Conditions: 9 pct Cr at 1600°C in bath at start of oxidizing period; 0.05 pct C in bath at end of oxidizing period; 10-ton furnace.
† Conditions: 15 pct Cr and 0.05 pct C at 1600°C in bath at start of oxidizing period; 10-ton furnace.

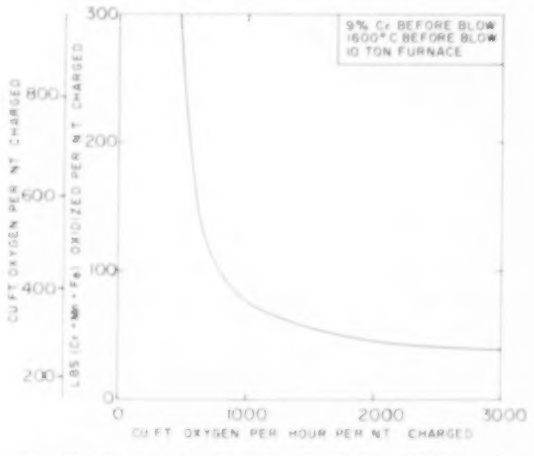

Fig. 15—Effect of blowing rate on metallic oxidation and oxygen consumption when decarburizing to 0.05 pct C.

of the bath. In view of the possible errors involved in the individual estimates, therefore, the agreement of estimated with observed carbon contents illustrated by Fig. 11 is quite satisfactory.

Another way to compare results calculated by means of the heat balance with actual ones is used in Fig. 12. Here the calculated effect of time on oxygen consumption is shown for 1 and 5-ton furnaces. The assumed starting conditions are 9.0 pct Cr and 1600°C, and the final carbon content is 0.05 pct. Selected data from Tables IV and V are compared with the calculated curves. The data selected are those from heats where the starting conditions and final carbon contents were reasonably close to the assumptions. They include those heats containing from 7 to 11 pct Cr and 0.25 to 0.42 pct C before the blow and from 0.04 to 0.06 pct C after the blow.

The method of calculation of the curves in Fig. 12 is described below in some detail as it is the same in principle for all the graphs that are discussed subsequently.

Furnace size = 1 ton.

1) General assumption of pct Cr before blow = 9
   Temperature before blow = 1600°C
   Pct C after blow = 0.05.
2) From Fig. 9 at 9 pct Cr and 1600°C, pct C before blow = 0.36, assuming the bath to be sufficiently oxidized for this relationship to be applicable.
3) Lb C oxidized = (0.36 − 0.05) x 20 = 6.2.
4) Cu ft O_2 for C = 6.2 x 16.1 = 100.
5) Special assumption—a series of temperatures after the blow; for example, 1750°C in this case.
6) From pct C = 0.05 and 1750°C, pct Cr after blow is 4.5, according to Fig. 9.
7) From pct Cr before = 9 and pct Cr after = 4.5, 780 cu ft O_2 is needed for chromium and iron oxidation, according to Fig. 4.
8) Trial solution, first step—estimate that time is 20 min:

Total O_2 for chromium and iron	780 cu ft
Total O_2 for carbon	100 cu ft
	880 cu ft
O_2 from air—20 min x 11.5 cfm, Fig. 6	230 cu ft
O_2 from oxygen	650 cu ft
Heat—carbon oxidation 100 x 0.18	18.0 kw-hr
Cr + Fe with O_2 (780-230) x 0.21	115.5 kw-hr
Cr + Fe with air 230 x 0.15	34.5 kw-hr
(Factors 0.21 and 0.15 kw-hr per cu ft O_2 from Fig. 3 at 4.5 pct Cr)	
Total input	168.0 kw-hr
Heat to raise temperature 1600°C to 1750°C, 150 x 0.43 (heat capacity from Fig. 8 for 20 min)	64.5 kw-hr
Heat to cover external losses	103.5 kw-hr
Heat loss rate, Fig. 10, 400/60	6.67 kw-hr per min
Second estimate of time 103.5/6.67	= 15.5 min.

9) Repeat calculation as in step 8, but using 15.5 min and so on until the desired degree of accuracy is obtained. In this case, 16.5 min was found in three steps.

Similar calculations were carried out for a sufficient number of assumptions of temperature after the oxygen blow to produce the curves in Fig. 12. The agreement of these calculated curves with actual observations is evident.

The results illustrated by Figs. 11 and 12 appear to demonstrate the reliability of these heat balance calculations for practical applications. Moreover, Fig. 12 further illustrates an evaluation of the heat balance in terms of rate of oxygen input during the oxidizing period. Consequently, application of the heat balance calculations to evaluate the specific relation of oxygen input rate to the chemical and thermal behavior of a heat of chromium steel during the oxidizing period on a quantitative basis is considered justified.

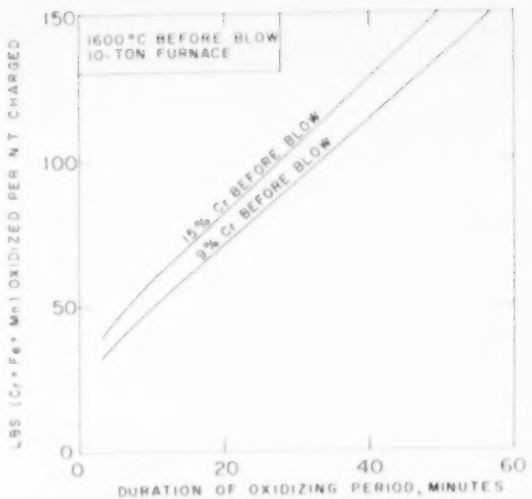

Fig. 16—Effect of time and chromium content of initial charge on metallic oxidation during decarburization of bath to 0.05 pct C.

Effects of Rate of Oxygen Input

By means of calculations similar in nature to those just described, graphs illustrating the major effects of oxygen input rate and the important significance of initial bath composition and temperature in relation to these effects have been derived. All of these graphs relate specifically to chromium steel heats containing 0.05 pct C at the end of the oxidizing period. Except as specified otherwise, they also refer to a bath temperature of 1600°C at the start of the oxidizing period. For the calculations, the assumption was made that prior to the injection of oxygen the bath was boiling, i.e., that the carbon content for the specified chromium content and temperature before the oxygen blow could be read from Fig. 9. It was also assumed that power is off during the oxidizing period except as noted, and that only a nominal amount of slag is present before the blow.

The effect of oxygen input rate on temperature of the bath at the end of the oxidizing period is shown in Fig. 13 for three different furnace sizes. Two important characteristics are apparent. One is the existence of a critical lower limit on blowing rate. If oxygen input rate does not exceed this critical rate, the bath will lose temperature and fail to decarburize satisfactorily. The other important attribute is the flattening of the curve at higher blowing rates. This flattening means that very high blowing rates do not result in proportionately high bath temperatures, provided the blow is stopped when the desired end carbon content is attained.

The next graph, Fig. 14, illustrates the effect of initial chromium content on the relation between oxygen input rate and bath temperature after the oxygen blow. There is little change in the critical blowing rate but a marked increase in the tempera-

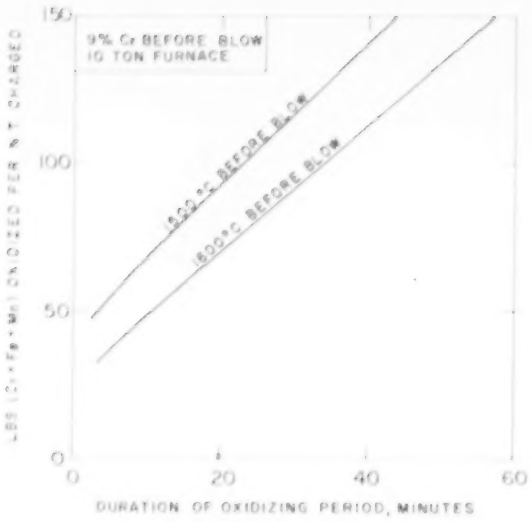

Fig. 17—Effect of time and initial temperature on metallic oxidation during decarburization of bath to 0.05 pct C

ture attained for higher chromium contents in the charge.

The amounts of metallic oxidation and, collaterally, oxygen consumption, are also markedly affected by blowing rate, as indicated by Fig. 15. Near the critical blowing rate a large fraction of the bath must be oxidized before the desired carbon level is attained. Higher rates of oxygen input substantially reduce metallic oxidation and oxygen consumption. Fig. 15 suggests that the theoretical minimum of metallic oxidation as well as oxygen consumption may be approached relatively closely with blowing rates that are both reasonable and practical.

The same effect is shown in Fig. 16, except that oxidation is plotted against time rather than rate to emphasize the fact that the total duration of the oxidizing period is important—not merely that portion of the period during which oxygen is actually being injected. It appears also from Fig. 16 that metallic oxidation is greater as the chromium content of the charge is increased. This is another facet of the effect noted in Fig. 14; the higher temperatures that result from higher chromium in the charge are produced by greater oxidation of the bath.

A lower temperature at the beginning of the blow adversely affects the amount of metallic oxidation, as shown in Fig. 17. For a given blowing rate, oxidation of the metal is increased on the order of 30 lb or more per ton for a 100°C lower starting temperature. Moreover, the duration of the oxidizing period is substantially increased. Thus, the practice used in some shops of beginning the oxygen injection before the charge is completely melted appears to be of doubtful economic value. The time saved by an early start for the oxygen blow must be paid for by increased oxidation and, consequently, by more time and materials in the reducing period of the heat as well as by prolongation of the oxidizing period itself.

Fig. 18, similar to Fig. 12 but for a 10-ton furnace and two different levels of chromium in the charge, illustrates the influence of charge composition upon the effect of blowing rate on equivalent oxygen—i.e., total energy—input. The increase in time and energy input at any given blowing rate caused by higher chromium in the charge is evident. This chart also suggests that in cases where the oxygen blow may be interrupted or delayed for any reason, such as by changing lances, taking samples, etc., application of electrical power could be desirable to avoid excessive prolongation of the oxidizing period with consequent increase in metallic oxidation and oxygen consumption.

Specific examples may clarify the quantitative effects of the variables that have been shown graphically. For these examples, two cases are considered, one being a chromium content of 9 pct and the other a chromium content of 15 pct in the bath at the start of the oxidizing period in a 10-ton furnace. The temperature of both baths at the start of the oxidizing period is assumed to be 1600°C. In each case, the time and oxygen expended, the amount of metallic oxidation resulting, and the temperature attained in decarburizing the bath to 0.05 pct C have been calculated for oxygen input rates of 1000 and 2000 cu ft per hr per net ton of charge with the results shown in Table VII.

In both cases, going from 1000 cu ft per hr per *NT* to 2000 cu ft per hr per *NT* has decreased oxygen usage by 25 pct, metallic oxidation by 40 pct, and time by 65 pct. Final bath temperature is up 20°C, but the increase in temperature is offset by the much shorter time the bath may be at maximum temperature.

The charts and examples just discussed are intended primarily for purposes of illustration and have practical application only under the specific conditions indicated. Similar charts and calculations, however, when made for the particular conditions that may prevail, should be of assistance in the design and control of more economical practices for melting chromium steel.

Summary

The heat loss rate of a 1-ton arc furnace melting chromium steel has been evaluated theoretically and experimentally and extrapolated by calculation to furnaces of larger size. These results were combined with those of previous investigations of the chromium-carbon-temperature and the slag-metal relations to evaluate the heat balance during the oxidizing period of chromium steel heats in terms of rate of oxygen input in relation to bath composition, bath temperature, and furnace size.

By means of this heat balance, the temperature and composition of the bath after an oxygen blow can be predicted if the rate of oxygen input and the composition and temperature of the bath at the start of the oxidizing period are known. Actual observations of 1, 5, and 25-ton stainless steel heats have confirmed the reliability of the calculations. The method has demonstrated the great sensitivity of the process to the operating variables that are readily controllable, such as temperature and composition before the oxidizing period, oxygen consumption,

Table VIII. Measurements on 1-Ton Furnace

Test No.	Temperature, °C		Time, Sec	Energy Added, Kw-Hr
	Before	After		
1	1630	1560	188	0
2	1560	1535	92	0
3	1535	1505	520	27.5
4	1600	1660	365	40.0
5	1525	1555	369	40.0
6	1555	1620	720	90.0
7	1620	1650	360	35.0

Table IX. Data for Calculation of Constants

Item	Material	Area, Sq Ft	Thickness, In.	Thermal Conductivity, Btu per Hr, Sq Ft, °F per In.	Specific Heat, Btu per Lb, °F	Density, Lb per Cu Ft	Diffusivity, Sq Ft per Hr
Bottom	Magnesia	13.4	14.5	25	0.30	170	0.0408
Sides	Magnesia	51.7	9.0	25	0.30	170	0.0408
Roof	High alumina brick	20.8	9.0	10	0.27	140	0.0220
Electrodes	Graphite	0.59	24.0	1000	—	—	—
Water-cooled surfaces	—	4.37					

duration of the oxidizing period, electrical power, etc. It has permitted the quantitative evaluation of the effect of normal errors in measuring these factors and has thus emphasized the great importance of their precise control in practice.

In general, higher oxygen input rates result in shorter oxidation periods, lower oxygen consumption, less oxidation of chromium and other metallic values, and higher bath temperatures. Moreover, for a given set of conditions, there is a critical oxygen input rate that must be exceeded if effective decarburization is to be attained. As furnace size increases, the specific critical rate per unit weight of the charge decreases, so that adequate rates may be practically attainable even in very large furnaces. At high oxygen rates the bath temperature reached for a given composition becomes relatively insensitive to further increase in rate. The major effect of still higher rates is to reduce the time the heat may be at high temperature—an effect that is of special interest from the standpoint of refractory life.

For a given rate of oxygen input, lower temperatures at the start of the oxidizing period substantially increase the duration of the oxidizing period and the amount of chromium, manganese, and iron oxidized into the slag. Higher chromium contents in the charge also increase the duration of the oxidizing period and the amount of metallic oxidation.

Although more accurate data and evaluations for specific conditions are needed, the relations that have been described are considered to provide the basis for the design and control of more economical melting practices for stainless steel.

Appendix I. Relationship Between Oxygen Used for Metallic Oxidation and Change in Chromium Content of Bath

The slags resulting from oxidation of chromium steels may be treated either as mixtures of FeO and $FeCr_2O_4$, or of $FeCr_2O_4$ and Cr_2O_3. The dividing line between these two types is at about 6 pct Cr in the bath.

Considering first the chromium-rich slags, it is assumed that 1 lb Fe and S lb Cr are oxidized. Converting pounds to mols, this leads to the following oxides:

$$FeCr_2O_4: 0.01791 \text{ mol}$$
$$Cr_2O_3: 0.00641S - 0.01194 \text{ mol}.$$

It can be readily verified that this mixture contains the postulated weights of iron and chromium. The combined oxygen in this amount of oxide is $0.01282S + 0.01194$ mol O_2. Using the conversion factor of 386.7 cu ft per lb mol, and dividing by the pounds of metal oxidized, the following is obtained.

Cu ft O_2 per lb metal oxidized =

$$(4.958S + 4.618)/(1 + S). \quad [9]$$

Eq. 3, given in the body of the report, relates pounds of metal oxidized per ton with initial and final chromium content. Multiplying Eqs. 3 and 9, and designating the cu ft O per ton of metal by Y, the following is obtained:

$$Y = 2000\,(Cr_i - Cr_f)\,(4.958S + 4.618)/(100S - Cr_f[1 + S]). \quad [10]$$

Eq. 4 in the body of the report results from a simple rearrangement of Eq. 10. The stoichiometry for the case where the oxides in the slag are present as FeO and $FeCr_2O_4$ is calculated by a similar procedure to obtain Eq. 5.

Appendix II. Apparent Heat Capacity of Charge and Container and Heat Loss Rate of Furnace

Experimental Approach—A series of empirical measurements were made in an experimental 1-ton furnace, in which temperature changes of the bath were measured by an immersion thermocouple, time was measured by a stopwatch, and electrical energy by an integrating kw-hr meter, with the results shown in Table VIII.

A multiple correlation performed on these data, wherein the entity *energy added* is regressed on the variables *time* and *temperature change*, leads to a heat loss rate of 300 kw at a mean temperature of 1580°C, and an apparent heat capacity of 0.35 kw-hr per ton, °C, for an average elapsed time of 6.2 min. The heat capacity of liquid iron[5] is 10 g cal per g mol, °C, or 0.19 kw-hr per net ton, °C. According to this, the effect of furnace lining, etc., has been almost to double the energy needed to raise the temperature 1°C. However, in view of the small number of pieces of data, the bands of confidence for heat capacity and heat loss rate are both quite wide and it would be well to check by another method the order of magnitude of the values found here. Also, the above measurements do not furnish the time-dependence of the apparent heat capacity.

Mathematical-Physical Approach—Solution of Heat Flow Equations—Another approach is to solve the heat flow equation

$$k\,\nabla^2 T = \partial T/\partial t \quad [11]$$

for suitable boundary conditions. In the above T is temperature, t is time, k is diffusivity, and ∇^2 is the Laplace operator.

For the outside of a furnace wall, the assumption of a constant temperature does not introduce a significant error. It can be shown that even during the longest heating periods considered in this study, less than 10 pct of the transient heat flow reaches the outside wall. For the inside, evolution of heat due to a more or less constant rate of oxidation of the charge is considered. This would correspond to an approximately constant rate of heat input so that, as a first approximation, the rate of temperature rise at the inside of the furnace might be regarded as constant. Making the further simplification that the curvature of the wall be disregarded, the furnace

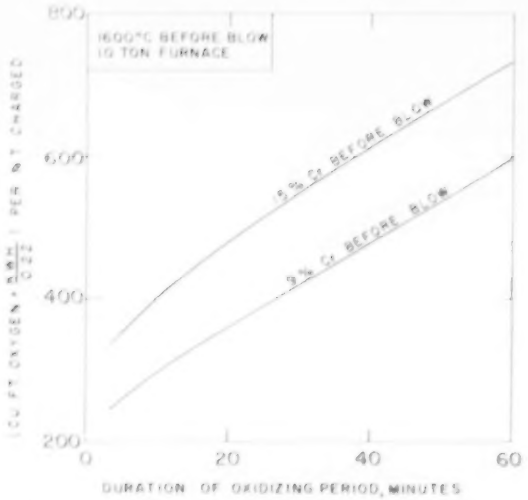

Fig. 18—Effect of chromium content of charge on duration of oxidizing period and oxygen consumption when blowing to 0.05 pct C.

lining can be considered as composed of elements of flat walls bounded by parallel planes. With these simplifications, the problem becomes the solution of the system

$$k\,\partial^2T/\partial x^2 = \partial T/\partial t \qquad [12]$$

with the initial and boundary conditions for $t = 0$, steady state $T = T_o + (x/L)(T_i - T_o)$; for $t > 0$ and $x = L$ (at inner surface), $T = T_i + a\,t$; and for $t > 0$, and $x = 0$ (outer surface), $T = T_o$. T_o is the outer temperature; T_i is the inside temperature at the start of the process; L is the wall thickness; x, the distance from the outside; a, the rate of temperature rise at the inside; and k, the diffusivity, defined as $\frac{\text{Thermal conductivity}}{\text{Specific heat} \times \text{Density}}$ in any set of consistent units.

The above system can be solved with the help of an analog computer, or analytically by use of solutions found in standard texts, e.g., reference 12.

If the following transformations are made to obtain dimensionless groups, $\theta = (k/L^2)t$, and $X = (x/L)$. The differential equation transforms to

$$\partial^2T/\partial X^2 = \partial T/\partial\theta \qquad [13]$$

of which the solution is, see reference 12, section 68, Eq. 2

$$T = A[(X^2 - X)/6 + X\theta + (2/\pi^2)\sum_{n=1}^{\infty}(-1^{n-1}/n^2)e^{-n^2\pi^2\theta}\sin(n\pi X)] \qquad [14]$$

where $A = a(L^2/k)$.

This solution represents the change in temperature from the initial steady state at $\theta = 0$. Differentiating with respect to X leads to the following expressions for the temperature gradient at the inside face $X = 1$

$$\partial T/\partial X_{x=1} = A[1/3 + \theta - (2/\pi^2)\sum_{n=1}^{\infty}(1/n^2)e^{-n^2\pi^2\theta}] \qquad [15]$$

The rate of heat flow into the refractory surface per unit area is $K\,\partial T/\partial x_{x=1} = (K/L)\partial T/\partial X_{x=1}$, where K is the thermal conductivity of the refractory.

The total quantity of heat flowing between times 0 and t is

$$Q = (LK/k)\int_0^{\theta}(\partial T/\partial X)_{x=1}\,d\theta =$$

$$\theta/3 + \theta^2/2 - (2/\pi^2)\sum_{n=1}^{\infty}(1/n^2)(1 - e^{-n^2\pi^2\theta}). \qquad [16]$$

If the change in temperature that occurs between times 0 and t is expressed by ΔT, then $\Delta T = at = (aL^2/k)\theta$, and the above expression can be transformed and rearranged to obtain for unit surface area

$$Qk/KL\,\Delta T = 1/3 + \theta/2 - (2/\pi^2)\sum_{n=1}^{\infty}(1 - e^{-n^2\pi^2\theta})/n^2\theta. \qquad [17]$$

Thanks to the term n^2 appearing in the denominator, the series converges quite rapidly even for small values of θ. The results of the calculations carried out for $\theta = 0.0001$, 0.001, 0.01, 0.1, and 1 are plotted in Fig. 19.

Application of Solution to 1-Ton Furnace—The heat balance may be written as follows

$$Q_t = [q_o + b(T - T_o)]t + C(T - T_o) + \Sigma Q_{refractory}. \qquad [18]$$

Here, Q_t is the heat input during time t; t is time during which heat is added; q_o is the heat loss rate at temperature T_o; T_o is the temperature at time 0; T is the temperature at time t; b is a constant giving the increase in the heat loss rate with temperature; C is the true heat capacity of the charge; and $\Sigma Q_{refractory}$ is the additional flow of heat into the refractories over and above the steady state flow.

Using the notation ΔT for $(T - T_o)$, this can be rewritten

$$Q_t = q_o t + [C + bt + \Sigma(Q_{refractory}/\Delta T)]\Delta T. \qquad [19]$$

The expression in square brackets has the dimensions of a heat capacity and includes the increase in the radiant heat loss rate through openings, etc., with rising temperature (the bt term), the increased heat flow into the refractories as the internal temperature rises (the $\Sigma Q/\Delta T$ term), and the true heat capacity of the charge, C. It is, therefore, the C_p', or *apparent heat capacity* of Eq. 6.

Data for the calculation of the constants in the above equation for the experimental 1-ton furnace are shown in Table IX.

For radiation to the water-cooled doors, the emissivity of the bath is assumed to be 0.90 and that of the doors 0.80. The bath, whose area is 12.5 sq ft, radiates to imaginary planes representing the openings in the refractory side walls. These planes, with a combined area of 4.4 sq ft, reradiate to the water-cooled doors through a 10-in. passage through the wall. This results in an effective emissivity factor of 0.50.

Radiant heat loss is then $Q(\text{radiant}) = 0.173 \times 0.50 \times 4.37 \times 10^{-8}[(^\circ F + 460)^4 - 560^4]$ Btu per hr.

The resultant values are:

Table X. Evaluation of Fig. 19

Furnace Part	Area, Sq Ft	K, Btu per Hr, Ft, °F	k, Sq Ft per Hr	L, Ft	$\frac{k}{L}$, (Hr)$^{-1}$	Area $\times \left(\frac{KL}{k}\right)$ Btu per °F	Kw-Hr per °C
Bottom	13.4	2.083	0.0408	1.29	0.02833	821	0.433
Sides	51.7	2.083	0.0408	0.75	0.7253	1981	1.046
Roof	29.8	0.833	0.0220	0.75	0.03911	591	0.312

Inside temperature	3000°F 1650°C	3300°F 1815°C	3600°F 1980°C
Q(radiant), Btu per hr	541,000	755,000	1,027,000
Q (radiant), kw	159	221	301.

Heat losses at 3000°F (1650°C) through the refractory, assuming an outside temperature of 300°F (150°C), are:

$$\text{Bottom} \quad 13.4 \times 25 \times \frac{3000-300}{14.5} = 62{,}400 \text{ Btu per hr}$$

$$\text{Sides} \quad 51.7 \times 25 \times \frac{3000-300}{9.0} = 387{,}800 \text{ Btu per hr}$$

$$\text{Roof} \quad 20.8 \times 10 \times \frac{3000-300}{9.0} = 62{,}400 \text{ Btu per hr}$$

Electrodes

$$0.59 \times 1000 \times \frac{3000-100}{24} = 71{,}300 \text{ Btu per hr}$$

583,900 Btu per hr (171 kw).

Then this estimate of the q_r of Eq. 19 is 171 + 159 = 330 kw.

The factor b of Eq. 19 can be estimated from the figures calculated for radiation. Over the 600°F range, the increase is 123 kw, or 0.24 kw per °F (0.42 kw per °C). For a given temperature increase during an oxygen blow, the average temperature only increases half as much as the final temperature, so b = 0.21 kw per °C. This linear interpolation results in a maximum error of 3 pct of the radiation losses as compared to integration of the T^4 relation over the temperature ranges shown.

Table XI. Determination of Heat Capacity

Time, hr	0.05	0.10	0.20	0.50	1.00	2.00
Time, min	3	6	12	30	60	120
Dimensionless time						
Bottom	0.00142	0.00283	0.00567	0.0142	0.0283	0.0567
Sides	0.00363	0.00725	0.0145	0.0363	0.0725	0.1451
Roof	0.00196	0.00391	0.00782	0.0196	0.0391	0.0782
Dimensionless heat, from Fig. 19						
Bottom	0.0270	0.0385	0.0555	0.088	0.124	0.177
Sides	0.0440	0.063	0.089	0.141	0.201	0.283
Roof	0.0320	0.0455	0.065	0.103	0.147	0.207
Kw-hr per °C						
Bottom	0.0117	0.0167	0.0240	0.0381	0.0537	0.0766
Sides	0.0460	0.0659	0.0931	0.1475	0.2102	0.2960
Roof	0.0099	0.0142	0.0203	0.0321	0.0459	0.0646
$\sum\left(\frac{\text{refractory}}{\Delta T}\right)$	0.0676	0.0868	0.1374	0.2177	0.3098	0.4372
0.21 × time	0.0105	0.0210	0.0420	0.1050	0.2100	0.4200
True heat capacity of steel	0.1900	0.1900	0.1900	0.1900	0.1900	0.1900
Apparent heat capacity, kw-hr per °C, NT	0.2681	0.3078	0.3694	0.5127	0.7098	1.0472

Note that from Fig. 19 the quantity $Qk/KL\ \Delta T$ can be obtained. The quantity sought for is the sum of all the $\Sigma Q/\Delta T$ for the whole refractory area of the furnace. Therefore, the factor k/L^2 is needed to transform actual time to the dimensionless time of Fig. 19, and the factor KL/k to convert the dimensionless heat to Btu per sq ft calculated for the different parts of the furnace. This is done in Table X.

Now, assuming a series of actual times, the corresponding dimensionless times can be computed, using the factor k/L^2. Going into Fig. 19 with this,

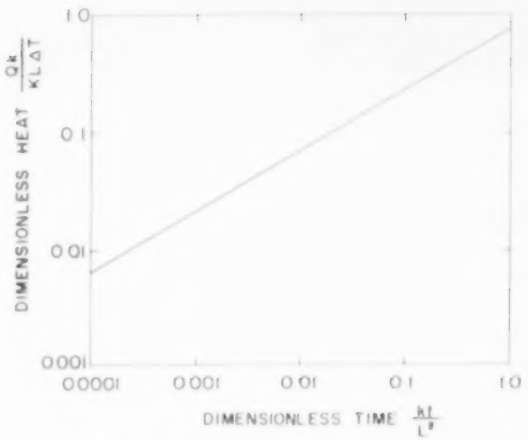

Fig. 19—Relation between time and heat flux into a solid with parallel walls, the temperature of one face increasing linearly with time.

the dimensionless heat value is obtained which, multiplied by the appropriate (area × $\frac{KL}{k}$) factor, gives the kw-hr per °C. The calculation is shown in Table XI. Adding the bt and C terms, the apparent heat capacity for 1 ton charged is obtained.

The results from Table XI are plotted in Fig. 7. In the first section of this appendix, it was found that, for an average time of 6.2 min, the apparent heat capacity was 0.35 kw-hr per °C. Fig. 7 shows 0.31 kw-hr per °C, which is in reasonably good agreement when due consideration is given to the inaccuracies in the directly measured value, and the numerous simplifying assumptions that had to be made to obtain the calculated one.

If Fig. 7 is examined, it will be noted that of the three items affecting the value of the apparent heat capacity, two must be influenced by furnace size; namely, transient heat flow into the refractories and radiant heat loss. The transient heat flow item will be roughly proportioned to the refractory area, and the radiant heat loss will vary with the area of openings and water-cooled surfaces. In order to obtain an estimate of the effect of these items on the apparent heat capacity of a larger furnace, for which detailed structural data were lacking, the assumption was made that the respective areas per ton of capacity are directly proportional to the heat loss rates per ton shown in Fig. 10. It is on this basis that the curves of Fig. 8 for the 5 and 25-ton furnaces were calculated from the data used to construct the curve for the 1-ton furnace.

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Discussion of this paper sent (2 copies) to AIME by July 1, 1957 will appear in AIME *Transactions* Vol. 212, 1958, and in JOURNAL OF METALS, October 1958.

Technical Note

Effect of Strain and Temperature on the Yielding of Copper and Nickel

by J. H. Frye, Jr., J. L. Scott, and J. W. Woods

THERE are at least two effects of temperature on the stress required to produce plastic flow. 1) Metals plastically strained for the same amount at different temperatures possess different stress-strain curves and different internal structures (e.g., nature and density of imperfections). 2) There is both experimental and theoretical evidence that the stress necessary to produce plastic flow may vary with temperature even though the internal structure remains constant.[1-3] Much of the data in the literature is difficult to interpret because these two effects are simultaneously present. In the work reported here, they are considered separately.

Standard 0.505 in. tensile specimens were prepared from high-purity Mond nickel and OFHC copper. Nickel specimens were annealed in hydrogen at 1150°C for 30 min and furnace cooled. This produced an average grain diameter of 1.4 mm. Copper specimens were annealed in vacuum at 525°C for 6 hr and furnace cooled. This produced an average grain diameter of 0.11 mm. Nickel tensile specimens were prestrained in tension at 500°K, whereas copper tensile specimens were prestrained in tension at room temperature. All specimens were cooled to 74°K and heated to room temperature. After these treatments all of the tensile specimens of a given set possessed identical structures.

All specimens were returned to the tensile machine and tested at various temperatures and constant cross-head speed. Many of the tensile curves showed well defined yields but, in order to minimize personal judgment, the yield was always chosen as the stress corresponding to 0.2 pct plastic deformation.

Results are summarized in the graph of yield vs temperature of test, Fig. 1. All of the specimens corresponding to any one line have had identical treatments and, therefore, have identical internal structures. Thus, each line gives the relation between yield stress and temperature for one constant internal structure. The lowest line, which is for annealed nickel, shows no measurable variation of yield with temperature. This is similar to Blewitt's[5] results on copper single crystals, but a variation in yield with temperature was found by Andrade and Henderson[6] in single crystals of nickel, and by Carreker and Hibbard[7] in annealed polycrystalline copper. The three other lines, which are for prestrained materials, show that there is a linear relation between yield stress and temperature when the internal structure remains constant.

Such a relation might be expected from a rate equation such as that of Kauzmann[1] on the assumption that the activation energy is either independent of or linear with temperature. These results would also be expected if the shear moduli of copper and nickel are linear functions of temperature for, as Cottrell and Stokes have pointed out,[8] *in all dislocation theories of strength the flow stress appears proportional to the shear modulus of the material.* In copper and nickel, since the modulus of elasticity decreases roughly linearly with increase in temperature,[9] it is probable that the modulus of shear also decreases approximately linearly with increasing temperature. A detailed discussion of the effect of these and other factors on the temperature dependence of flow stress in face-centered-cubic metals has recently been given by Seeger.[4]

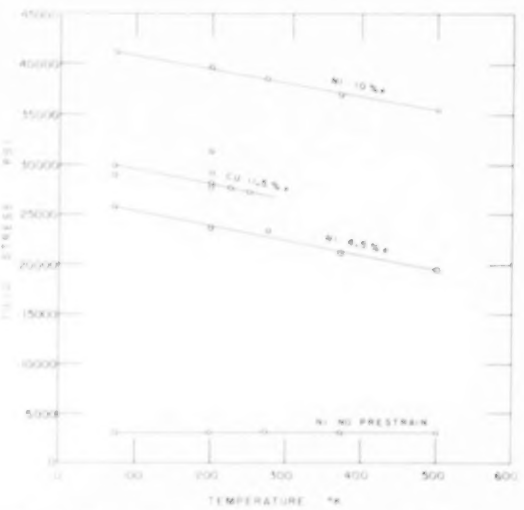

Fig. 1—Flow stress vs temperature for annealed and prestrained Mond nickel and copper. Percentages refer to plastic elongation by tension.

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TN 384E. Manuscript, Dec. 1, 1955.

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AIME NEWS

Metals Conference in Los Angeles

B. S. Mesick, Conference Chairman

The Ambassador Hotel in Los Angeles will be the headquarters for the Regional Reactive Metals Conference, May 28-29. Sponsored by the AIME Southern California Section, the meeting will be concerned with the resources, production, fabrication, properties, and use of such metals as: beryllium, boron, cerium, columbium, hafnium, lanthanum, lithium, molybdenum, titanium, thorium, among others.

A number of prominent companies have prepared exhibits of equipment important in the mining and processing of reactive metals and examples of fabrication techniques.

To keep the distaff happy, the WAAIME Hospitality Committee will have representatives at the Registration Desk to assist with plans for shopping trips or sightseeing tours. The ladies are also urged to attend the luncheons and dinner.

Registration is $3.00 for AIME members and $5.00 for nonmembers; students will be admitted free. The proceedings of the Conference will not be published. However, where available, reprints of talks will be distributed to registrants.

(See Program on page 719)

Steel Committee To Hold Annual Meeting

When the AIME Converter Steel Committee holds its annual meeting on May 15, the members will be guests of the A. M. Byers Co. in Ambridge, Pa. The morning session will be devoted to an inspection tour of the company's converter plant.

The hosts have arranged a luncheon for their visitors, to be served at noon. In the afternoon, a technical session will be held.

Transportation to Ambridge is by chartered bus which will leave the Penn-Sheraton Hotel, Pittsburgh, at 8:30 am, returning at 6 pm. Reservations must be made in advance.

100th Anniversary Of Belgian Magazine

JOURNAL OF METALS congratulates the *Revue Universelle des Mines* on the occasion of its 100th anniversary in May. The *Revue Universelle des Mines* is the organ of the Association des Ingénieurs sortis de l'École de Liège (association of graduates of the University of Liège). It is the oldest Belgian technical periodical.

For this occasion, in response to a suggestion from His Majesty, a special international conference has been organized under the title *Scientific Research and Industry*. The conference, under the co-direction of an old friend of AIME, Pierre Coheur, will feature speakers from six European countries.

Directory

A new all-Institute directory was announced in the April issue. Members may obtain copies of the directory without cost by using the coupon that appeared on page 616, Journal of Metals, April 1957, or by letter. Please use the coupon if possible.

Nominating Committee of the Metallurgical Society of AIME

The Nominating Committee of the Metallurgical Society of AIME is charged with the duty of selecting a nominee for the position of Vice President of the Society. This nominee, if elected, will serve as Vice President from February 1958 to February 1959, and will automatically succeed to the office of President of the Metallurgical Society at the end of his term as Vice President.

The nominee will succeed our current Vice President, Mr. Walter R. Hibbard, Jr., who will be President of the Society from February 1958 to February 1959.

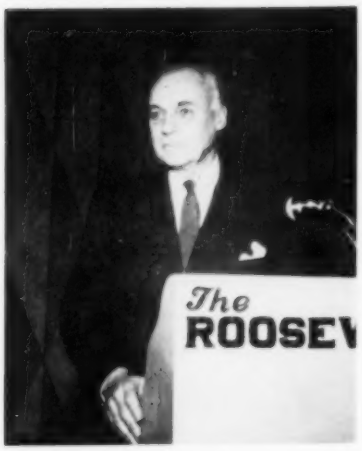
The Committee is deeply concerned with its obligation to nominate an outstanding member to this most important post. This individual should be a man with unusual qualifications. He should be chosen regardless of Division or Section affiliation.

To accomplish this task, the Committee is open to suggestions from the Society membership. Please submit names of possible candidates to any member of the Nominating Committee prior to May 20.

Nominating Committee

A. W. Thornton, *Chairman*
C. S. Barrett
John Chipman
Morris Cohen
T. D. Jones
C. C. Long
R. R. McNaughton
J. H. Scaff
T. S. Washburn

AIME President C. E. Reistle, Jr. receiving proclamation from New Orleans Mayor de Lesseps S. Morrison declaring "AIME Week."



B. Brewster Jennings who was the principal speaker at the All Institute technical session Tuesday afternoon.

New Orleans Annual

The 1957 renewal of the Annual Meeting held this year at New Orleans set a new record for out-of-New York meetings with registration of over 3700, including 900 ladies. The meeting featured many innovations including the All-Institute Technical Session on Tuesday afternoon and marked the emergence of the three Societies within the Institute, the Society of Mining Engineers, the Metallurgical Society, and the Society of Petroleum Engineers.

Attendance was excellent at both technical sessions and social events, while some of the meetings of the three branches, now societies, taxed New Orleans' capacity to the utmost.

It is to the credit of the Delta Section sponsoring the meeting and acting as host that a crowd of this magnitude was handled as smoothly as it was. Activity actually began Friday afternoon with the meeting of the Interim Committee of the Council of Section Delegates and continued Saturday and Sunday with delegates meetings, council meetings, committee meetings, and on Sunday with the general session of the Mineral Industry Education Division. The All-Institute program officially opened at noon on Monday with the traditional welcoming luncheon, whose guests heard Joseph C. Morris, vice president of Tulane University, deliver a concise and clear picture of the accomplishments to be expected for the geophysical year. That evening the social events were started off at the All-Institute cocktail party held at the Jung Hotel. This was followed by the stag dinner-smoker at 7:30 pm that night at the Roosevelt Hotel, which was attended by nearly 1,200.

Part of the estimated crowd of 1500 streaming aboard the SS President for the informal dance on Tuesday night.

All-Institute Session

As an innovation, an All-Institute Technical Session, to be followed by the Institute business meeting, was scheduled for Tuesday afternoon with no conflicting sessions or meetings permitted. The session was unusually well received, attendance exceeding 1000 as President C. E. Reistle, Jr. started off the meeting

Joseph C. Morris, vice president of Tulane University, addressed the welcoming luncheon guests.

Introducing Directors and Officers seated at the head table during the welcoming luncheon in New Orleans.

Meeting Breaks Records

with a review of the state of the Institute. The text of President Reistle's remarks may be found on pages 574 to 576 of the April issue. Following President Reistle, the guests heard B. Brewster Jennings, chairman of the board, Socony Mobil Oil Co. Inc., speak on *Mankind's Stake in Middle East Oil*. Following Mr. Jennings' review of the situation in this politically troubled vital energy source area, the members attended the annual AIME business meeting which was held in the same room. In addition to a brief summary by the President, each of the staff members delivered his part of the annual report.

Branch Dinners

Tuesday evening each of the branches—Mining, Metallurgy, Petroleum—held its branch dinner, and then the Institute members reconvened on the steamer SS President at 10:00 pm for the All-Institute formal dance. The steamer President leisurely cruised down the river with over 1500 guests seated on its five decks in addition to those on the dance floor. The committee had provided entertainment as well as dance music for those who came aboard and dancing continued after the steamer docked at 1:00 in the morning for those who wished to leave early.

Annual Banquet

Wednesday evening it was off with the old and on with the new, as well as a moment for the profession to honor achievement by top men in its field. President Reistle was chairman and toastmaster of the banquet which presented the Hoover Medal (sponsored by the Four Founder Engineering Societies) to Herbert Hoover, Jr., whose remarks and response to the award presentation may be found on page 511 of this issue. The Alfred Noble prize, also sponsored by the Four Founder Engineering Societies (as well as the Western Society of Engineers) went to Mohamed Mortada. The following five AIME awards were presented at the banquet: the James Douglas Gold Medal to Russel B. Caples; the Anthony F. Lucas Gold Medal to John E. Brantly; the Charles F. Rand Gold Medal to Andrew Fletcher; the Robert H. Richards Award to Antoine M. Gaudin; and the Benjamin F. Fairless Award to Leo F. Reinartz. Following the award presentations, Toastmaster Reistle introduced incoming President Grover J. Holt, who delivered the principal address. Following the banquet, the presidential receiving line formed and guests then returned for dancing.

Field Trip

One of the features of this year's Annual Meeting was a scheduling on Friday of extensive field trips, by the Mining group to the Freeport Sulphur Company operations along the Gulf Coast and by the Metals Group to the Chalmette Works of Kaiser Aluminum and Chemical Corp. With field trips on Friday and the meeting starting on Friday, this year's Annual Meeting was truly more than a week long, and registrants found day to day events closely packed despite original limitation on the number of sessions, particularly of concurrent sessions.

As an experiment, with its innovations, and with its inauguration of the three new Societies, the 1957 Annual Meeting at New Orleans marked the beginning of a new era in AIME history.

John E. Sherborne discussed the challenge to today's petroleum engineering graduates at the MIED general session Sunday evening.

John C. Kinnear, Jr., first President of the Metallurgical Society of AIME, introduced the new Society at the Metals Branch dinner held at the Jung Hotel Tuesday night.

"Old" Metals Branch Dinner Initiates "New" Metallurgical Society of AIME

Launching of the Metallurgical Society of AIME was celebrated at the last Annual Dinner of the former Metals Branch. Following official launching of the new Society by the AIME Board of Directors at 4:00 pm, Tuesday, February 26, in New Orleans, the Metallurgical Society was pronounced ready for operation by A. W. Thornton, 1956 Chairman of the Metals Branch. Mr. Thornton pointed out that the new Society could look forward to a great future. It would maintain the same three operating divisions as existed in the Metals Branch—EMD, IMD, and ISD.

John C. Kinnear, Jr., first president of the Metallurgical Society of AIME, and Walter R. Hibbard, Jr., Vice President and President-Elect, were introduced to the dinner guests. A news highlight was the announcement of the appointment of Robert W. Shearman, former Metals Branch Secretary and now Secretary-Treasurer of the Metallurgical Society, as Assistant Secretary of AIME.

President-Elect of the Institute, Augustus B. Kinzel, brought greetings from the AIME President and from the other two Societies of the Institute.

ISD and IMD Awards

The Iron and Steel Division and the Institute of Metals Division presented their annual awards at the dinner. John Chipman, Chairman of ISD, presented the J. E. Johnson, Jr. Award to Raymond W. Sundquist, "For his ability as a Blast Furnace Operator in assisting in the development of new techniques and his contributions to the Blast Furnace Literature." Mr. Chipman presented the Robert W. Hunt Award, in absentia, to Arthur Tix of Bochum, Germany, for his paper, *Production-Scale Vacuum Steel Degassing*. Charles S. Barrett, Chairman of IMD, awarded the Mathewson Gold Medal to Paul Gordon for his paper, *Microcalorimetric Investigation of Recrystallization in Copper*.

Discussion of the status of the government-supported basic research program in metallurgy was one of the highlights of the Metals Branch program. Participants as moderators and panelists at the Monday afternoon session were: left to right (seated)—J. W. Poynter, W. J. Harris, Jr., R. F. Mehl, and J. J. Harwood; left to right (standing)—P. R. Kosting, W. H. Woodward, Charles Yost, L. M. McKenzie, E. E. Litkenhous, and Edward Epremian.

ONR Receives Citation

The Office of Naval Research, on its 10th anniversary, was cited by AIME for "effective and continuing support of fundamental research in metallurgy." Robert F. Mehl, head, Dept. of Metallurgical Engineering, Carnegie Institute of Technology, read the citation addressed to Rear Adm. Bennett. In making the presentation, Dr. Mehl stated that "AIME has long been aware of the . . . admirable activity, by the government, during the last 10 years, in supporting basic research . . . to provide a most needed foundation for that technical know-how so characteristically American." Dr. Mehl added that since the ONR was the precursor of this whole effort, their essential role deserved the proper acknowledgment.

Capt. A. B. Metsger, who accepted the citation, pointed out that ONR has supported a strong program on materials research, particularly metallurgy. He continued, "This has been self-interest . . . because nearly every demand for increased operating capability of surface ships, submarines, aircraft, and missiles is ultimately . . . a requirement for improved materials . . . The nuclear-powered ships could not be built without solution of many metallurgical problems. . . . in reactor technology. The F8U, the Navy's newest and fastest fighter, is the first naval aircraft to use significant amounts of titanium, a metal made useful through a strong research and development program."

Speaker of the evening was Clayton Rand, Editor of *The Dixie Guide* and owner of the Dixie Press at Gulfport, Miss. His message on the South was presented in a brilliantly witty manner which was enjoyed by all.

EMD Luncheon

Grover J. Holt, 1957 AIME President, brought warm greetings to the EMD Luncheon Meeting presided over by outgoing division chairman, J. C. Kinnear, Jr.

Following the introduction of the head table, 1957 EMD Chairman, Bruce W. Gonser, took over the gavel and presented a plaque to former chairman Albert W. Schlechten in commemoration of his service to the division. The Extractive Metallurgy Division Award for the best paper of the year was presented to R. C. Bell, G. H. Turner, and E. Peters, for their paper, *Fuming of Zinc from Lead Blast Furnace Slag—A Thermodynamic Study*.

After savoring another exotic creole creation, members of the division were treated to a most entertaining presentation of a serious theme, *New Horizons—New Responsibilities* by speaker J. K. Richardson.

American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc.
29 West 39th Street, N. Y., N. Y.

Office of the President

February 26, 1957

Rear Admiral Rawson Bennett
Chief of Naval Research
United States Department of the Navy
Washington 25, D. C.

Dear Admiral Bennett:

In recognition of the effective and continuing support of fundamental research in metallurgy and the physics of metals, the American Institute of Mining, Metallurgical, and Petroleum Engineers wishes to express its appreciation to the Office of Naval Research during this, its tenth anniversary. Instrumental in the training of over three hundred and fifty graduate students and the prosecution of research projects that resulted in over seven hundred and fifty technical papers, the Office of Naval Research program in metallurgy has made a significant contribution to the metallurgical profession. This program of research has demonstrated that there can be a continuing, effective partnership between the Government, the universities, and other research groups in the pursuit of significant basic investigations. The publications stemming from this work have reflected credit on the investigators and the Office of Naval Research. The journals of the American Institute of Mining, Metallurgical, and Petroleum Engineers have served as the publication media for many of the Office of Naval Research papers.

The American Institute of Mining, Metallurgical, and Petroleum Engineers is pleased to have this opportunity to cite the Office of Naval Research for effective support of basic research in metallurgy.

Sincerely yours,

C. E. Reistle, Jr.
President

CER:MDS

The citation to the Office of Naval Research was presented at the Metals Branch dinner by Robert F. Mehl shown here with Capt. A. B. Metzger, USN, who received the citation.

Extractive Metallurgy Division Session Reports

Aluminum and Magnesium—In this session the papers were concerned with the following: the problems facing governmental agencies in storing the magnesium stockpile, a coke particle size distribution that minimizes cracks in Soderberg electrodes for aluminum smelting cells, and the encouraging discovery that no unusually harmful constituents were detected by mass spectrometric analysis of fumes from aluminum smelting cells.

In the joint meeting with the ISD refractories group, a lively discussion came from the two papers concerning refractories for aluminum melting. Representatives of the aluminum companies welcomed the presentation but said that a much more vigorous program would be necessary for the refractory companies to meet the needs of the aluminum industry. Approximately 65 persons attended the session.—*A. S. Russell.*

Copper Smelting—On Tuesday morning, a capacity audience of over 100 heard of both the new and the old in copper smelters, when papers were presented on two new copper smelters, Gaspe and San Manuel, together with a paper on the history and present practice at the El Paso smelter.

The paper on *The Gaspe Copper Mines Smelter* was presented by G. C. McKerrow, who outlined the chief features of interest. The remote location and the climate, with its 250 in. of snow a year, presented unusual problems in construction. The smelter metallurgy follows modern wet-charging practice, using a reverberatory furnace, two converters, and an anode furnace, with a design capacity of 3300 tons of copper a month. Interesting features of operation are the use of a truck for hauling molten slag, a very favorable furnace fuel ratio, and extremely low slag losses.

The paper on *The El Paso Smelting Works of A.S.&R.* by T. J. Woodside and Ben Roberts was presented by Mr. Woodside. This plant, founded in 1887 as a small lead smelter, now ranks as one of the important custom smelters in the U. S., treating a wide variety of lead and copper ores and concentrates from Mexico and the Southwest as well as from foreign sources. Current production amounts to 7500 tons of lead, 6000 tons of copper, and 3500 tons of zinc fume a month.

In the absence of the author, R. C. Wilson, the paper on *The San Manuel Smelter* was read by J. N. Anderson. This, the newest of the smelters in the Southwest, was built with a design capacity of 6000 tons of copper a month and was blown in during January 1956. Equipment consists of storage and handling facilities for concentrates and fluxes, a wet-charged reverberatory furnace, three converters, and a cylindrical anode furnace, together with necessary auxiliary equipment. Two interesting features of the reverberatory furnace are the separately fired preheater for combustion air and the use of the suspended basic roof, an innovation in the Southwest.—*J. N. Anderson.*

One of the highlights of the EMD luncheon was a presentation of certificates to R. C. Bell, G. H. Turner, and E. Peters for the EMD Award. Making the presentation was J. S. Sullivan.

Hydrometallurgy—The Wednesday afternoon session presented a unique combination of new materials for old processes, and old materials for new processes. W. W. Minkler of the Titanium Metals Corp. gave very interesting data on the influence of metal ions on corrosion resistance of titanium in acid media. During the discussion, Dr. Fassel, of the Howe Sound Co., re-emphasized the importance of oxygen in inhibiting titanium corrosion in acid media. R. L. Pearson, formerly at the University of Utah, now employed at Oak Ridge, ably presented a paper co-authored by M. E. Wadsworth of the University of Utah on the dissolution of UO_2 in carbonate solutions. The overall reaction was postulated to be the diffusion of undissociated H_2CO_3 and its competition with O_2 at the adsorption sites. The slow step was reported to be the rearrangement of adsorbed oxygen on UO_2 surfaces.

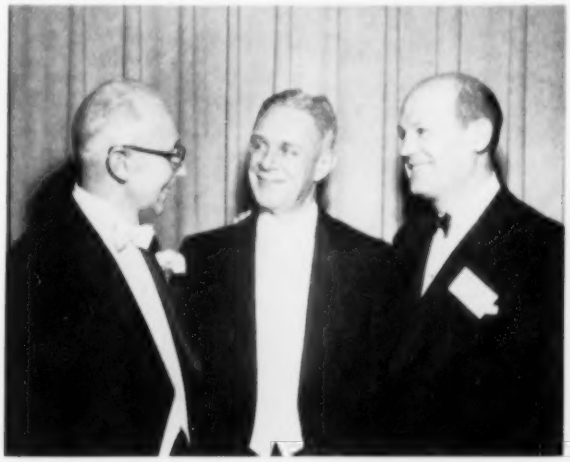
F. M. Stephens, Jr., L. W. Coffer, and J. W. Cookston of Battelle, reported a unique series of investigations on carbonyl formation at the surfaces of metallic iron, nickel, and cobalt, in which the nominally slow reaction rates were greatly accelerated by imposing high temperature and pressure autoclave conditions on the system. The possibility of adapting this process to laterite ore extraction aroused the interest of E. B. Mancke of Bethlehem Steel, among others.

J. Y. Welsh and D. W. Peterson of Manganese Chemicals Corp. reported on plant operations of the Dean-Leute ammonium carbonate process of manganese production from low grade domestic ores. The exceptionally high grade manganese carbonate produced permits production of battery grade MnO_2, ferrograde manganese, and specialty products from domestic raw materials.

The session closed with a paper by R. V. Lundquist of the USBM in Boulder City on the application of a plate and frame press to the electrolytic regeneration of H_2SO_4 and NaOH from the waste sodium sulfate produced in the acid leaching of manganese ores.—*H. Gordon Poole.*

Uranium Hydrometallurgy—At the Wednesday am session solvent extraction occupied the attention of an audience of approximately 100 listeners, as three speakers covered various aspects of the subject. A. M. Ross, National Lead Co., explained why so many Colorado Plateau mills have adopted or are considering the adoption of solvent extraction for uranium recovery. The principal advantages of solvent extraction are simplicity, versatility, ease of operation, and freedom from interferences. E. H. Crabtree, Colorado School of Mines Research Foundation, presented a very able discussion of the solvent extraction process and the considerations influencing the selection of process reagents.

LEFT: A. W. Thornton, outgoing Chairman of the Metals Branch was toastmaster at the dinner which launched the Metallurgical Society of AIME. RIGHT: W. R. Hibbard, Jr., and Leo F. Reinartz discuss the Benjamin F. Fairless Award which went this year to Mr. Reinartz for "his distinguished achievement in production and in technology."



LEFT: John Chipman, outgoing ISD chairman, presents the J. E. Johnson, Jr., Award to Raymond W. Sundquist at the Metals Branch Dinner. RIGHT: President-Elect Augustus Kinzel (center) with the two principal Metals Branch lecturers. Morris Cohen IMD lecturer is on the right, and E. S. Davenport, who delivered the Howe Memorial Lecture, is on the left.

J. D. Moore, Vitro Uranium Co., followed with a description of studies for the design of a large scale solvent extraction facility to be constructed by Vitro for production of uranium concentrate at Salt Lake City.

The latter part of the meeting was concerned with carbonate leaching of uranium ores. B. G. Langston, Battelle Memorial Institute, discussed the ammonium carbonate leaching process, which he indicated is technically attractive, but not applicable to all ores. R. G. Beverly, National Lead Co., presented a stimulating comparison of atmospheric and pressure leaching. Pressure leaching offers the advantage of greatly reduced leach contact time, but only at probable expense of increased capital investment together with the possibility of corrosion problems.—*J. S. Breitenstein.*

Fused Salt Electrolysis—This session, attended by about 100 people, demonstrated the increasing interest in fused salts as a medium for electrorefining refractory metals. Three of the six papers on the program were concerned with this subject. J. R. Nettle gave further details on the titanium refining process which was first described before this group at the New York meeting last year. His recent results in removing the impurities from synthetic binary alloy anodes showed considerable promise for the process.

W. W. Gullett described another process for electrorefining titanium by fused salt electrolysis, and also reported excellent results with a variety of contaminants. S. Senderoff described a process for electrorefining of molybdenum and indicated that high temperatures and low current density favored the efficiency of refining.

In a complete and detailed paper, J. L. Wyatt explained the operating procedure, equipment, and preparation of materials for producing electrolytic thorium. Two very interesting papers on theoretical subjects were also presented. S. Mellgren discussed the equilibria between titanium metal and various valence states of titanium ions in molten $SrCl_2$-NaCl melts. He concluded that further work was required to establish the nature of the complex ions which probably exist in the system.

H. Bronstein described some very accurate conductivity determinations on solutions of potassium metals in potassium chloride. On the basis of results still incomplete, the possibility of electronic conduction and the existence of *conduction bands* in the molten system was suggested as a possible explanation of the observed conductivities.—*S. Senderoff.*

(Continued on page 717)

LEFT: J. K. Richardson was the principal speaker at the EMD luncheon on Wednesday noon at the Jung Hotel. RIGHT: Presentation of plaque to A. W. Schlechten, Past Chairman of EMD by J. C. Kinnear, Jr., new President of the Metallurgical Society of AIME.

LEFT: E. S. Davenport, who delivered the Howe lecture, and Dr. Chipman, outgoing ISD chairman. RIGHT: Mohamed Mortada, shown here with Past President Reistle, had the unique distinction in recent Annual Meeting history of receiving both the Alfred Noble Prize sponsored by the Four Founder Engineering Societies, and the Rossiter W. Raymond Memorial Award established by AIME.

LEFT: Charles S. Barrett awarding the Mathewson Gold Medal to Paul Gordon at the Metals Branch dinner. Mr. Barrett was the outgoing chairman of IMD. RIGHT: Other guests at the same dinner were: Mr. and Mrs. A. H. Smith, and Dr. and Mrs. Augustus Kinzel.

Institute of Metals Division Session Reports

Physical Metallurgy of Iron and Steel—This session opened with a paper on *Flaking of Heavy Alloy Steel Sections* by C. R. Garr and A. R. Troiano. Presented by Dr. Garr, Westinghouse Atomic Power Laboratories, the paper revealed that large section sizes can be produced flake-free, in spite of relatively high hydrogen contents, by isothermal transformation in the bainite range where complete decomposition of austenite could not be obtained. The profound effect of transformation stress on the propensity to flaking was emphasized by this and other similar experiments.

H. M. Otte, Birmingham University, presented data demonstrating that the scatter in the habit planes in a 2.8 pct Cr, 1.5 pct C steel is much greater than the experimental error and thus must be considered real. This scatter was attributed to slip in austenite and to the imperfect structure of martensite. Evidence for slip in martensite also was discussed.

E. J. Whittenberber, U. S. Steel Corp., discussed an investigation of the $\gamma/\gamma+\delta$ phase boundary in Cr-Ni-Mn-N steels. Nitrogen and nickel were found to contribute strongly to austenite formation while chromium, and to a lesser extent manganese, promoted the formation of δ ferrite.

J. Philibert, Institut de Recherches de La Siderurgie, presented an extremely interesting discussion of an electron probe microanalyser and its application to studies of segregation, selective oxidation, identification of carbides and nonmetallic phases, and to diffusion in complex systems.

J. B. Austin, U. S. Steel Corp., session chairman, presented the paper on *An Electron Diffraction Study of Flake Graphite Extracted from Molten Pig Iron* for the authors, K. Niwa and G. Shimaoka, Hokkaido University, Japan. It was demonstrated that single graphite flakes consist of a mixture of the α and β forms or a more disordered structure.—*J. B. Austin.*

Iron and Steel Division

Gases in Steel—An interesting session on the thermodynamics and kinetics of reactions of liquid steel with nitrogen, hydrogen, and carbon monoxide provided ample opportunity for discussion by those attending the session; as many as 140 people were present. The broad interest in the subject was indicated by the presence of many physical metallurgists as well as those interested primarily in iron and steel making.

F. C. Langenberg opened the meeting with a summary of the known, reliable information on the solubility of nitrogen in liquid alloy

(Continued on page 718)

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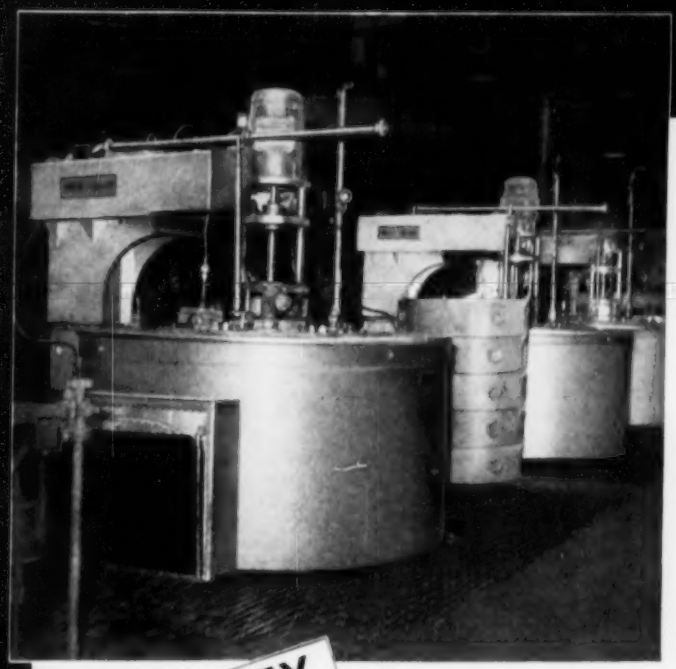

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AROUND THE SECTIONS

Mirth and merriment were the order of the day at the Annual Dinner-Dance held by the Woman's Auxiliary of the Chicago Section in the Shoreland Hotel.

• The Women's Auxiliary of the **Chicago Section** held their annual dinner-dance at the Shoreland Hotel, January 26. A record attendance of 230 attested to the success of the affair organized by Mrs. Alex Jolley and her committee.

On February 6, the Section met at the Chicago Bar Assn., the new chairman, Michael Tennenbaum, of Inland Steel Co., presiding. Featured speaker of the evening was Frank M. Richmond of Universal-Cyclops Steel Corp. who presented an interesting paper on the current production of vacuum melted steel, particularly the superalloy steels and high alloy materials. Mr. Richmond pointed out that vacuum melting affords a greater insight into the effect of trace elements on the physical values of the metals produced. This is primarily true with the effects of gases and alloying elements such as boron, zirconium, and titanium. A lively discussion period followed.

• The **Ajo Subsection** meeting on January 10 at the Copper Coffee Shop, Ajo, Ariz., featured a talk by G. H. Reeveare, metallurgist with the USBM in Tucson. He explained Fluo-Solids roasting experiments being conducted at the University of Arizona Testing Laboratory. The speaker's informative talk generated a lively discussion. A report on the Arizona Section Meeting, December 3, was then given by various members who attended: Frank Denny, Ralph Herndon, Troy Hinton, Bob West, and Jim Lattrell.

The Subsection met again on February 14, at the Copper Coffee Shop. Two guests were introduced: Thomas E. Diehl and Frank Galloway, both of Phelps Dodge Corp. After dinner the group watched a showing of the film, *This Is Mi Vida*, which answered many questions about uranium mining in Colorado.

• The **Southeast Section's** Coffee and Doughnut Session was held on February 11, at the Thomas Jefferson Hotel in Birmingham. At that time, members heard a talk by James R. Dudworth, Dean, College of Engineering, University of Alabama. His topic was *The Status of Engineering Education.*

• The **Washington, D. C.** Section gave their 31st Annual Oyster Party on February 5, at the National Press Club. There were all the oysters they could eat—on the half shell, panned and fried, and oyster stew—all tasty enough to "satisfy the most particular palate."

No formal speaker was scheduled but several members gave short talks on their trips to faraway spots. Clarence Fredell started the ball rolling with an account of his recent visit to a large manganese deposit in Brazil.

The Section met again at Hotel Willard on February 20, Engineer's & Architects' Day. Keynote speaker for the luncheon was Eric Walker, president of The Pennsylvania State University. At this meeting awards were presented to outstanding young local scientists and engineers.

• The **El Paso Metals Section** met at Hotel Cortez on February 13, to hear Charles Steen, President, Utex Mining Corp., Moab, Utah. After being introduced by Marion S. Bell, Section chairman, Mr. Steen spoke about uranium mining. His talk was followed by the screening of a film, *This is Mi Vida.*

(Continued on page 720)

Session Reports

(Continued from page 717)

steels. He presented a relatively simple method for predicting the solubility of nitrogen in liquid complex-alloy steels. The results of an experimental study of the solubility of nitrogen in Fe-Mo-V steels at 1600°C was reported by N. A. Parlee and V. C. Kashyap. Next, a systematic study of operating variables on the hydrogen content of the steel bath of an open hearth furnace was presented by J. H. Richards.

The meeting closed with a paper on the rate of C-O reaction in liquid iron by S. R. Seagle, N. A. Parlee, and R. Schuhmann. A unique experimental technique avoided some of the difficulties inherent in nucleation of bubbles, present in previous studies.—*John F. Elliott.*

Manufacture of Cold-Rolled Steel Sheets—The capacity audience at the joint ISD-IMD session arranged by the ISD Mechanical Working Committee was rewarded with a well balanced program of four papers.

H. C. Rogers, General Electric Co., presented a fundamental approach based on dislocation theory, to control of yield point, strain-aging and age-hardening phenomena in mild steel. A theory was introduced and demonstrated showing how the yield point can be eliminated, and strain-aging controlled by proper attention to the distribution of residual stresses introduced during the temper-rolling of mild steel sheet. This theory offers the possibility of a new approach to the problem of producing nonaging strip steel beyond the current practices of controlling steelmaking variables.

J. F. Griffin, of U. S. Steel Corp., described a laboratory testing procedure which has been useful in screening out unsatisfactory lubricants for high speed cold rolling mills. The need for further work along this line was pointed out by Mr. Griffin in his statement that modern cold rolling mills are operating considerably below their maximum attainable speed only because of the inadequacy of available rolling lubricants. Before new developments in lubricants can be tested on mill equipment it is essential to know that no damage will result.

Great interest was shown in the two papers describing a new use for boron in controlling strain-aging in low carbon steels. L. R. Schoenberger, Jones & Laughlin Steel Corp., reported the development of nonaging semi-killed steel made with ladle additions of ferroboron. The steel produced by this practice had excellent ductility and softness. Ingot-to-finished yield and surface quality were claimed to be superior to aluminum-killed steels. E. R. Morgan, and J. C. Shyne described a chemically capped steel developed at Ford Motor Co.—*G. H. Enzian.*

Program—Los Angeles Reactive Metals Conference

(Data as of May 1, 1957. Functions not otherwise identified are joint sessions of the Metallurgical Society and Society of Mining Engineers.)

TUESDAY, MAY 28

Registration

8:30 am — Ambassador Hotel

Titanium, Zirconium, Hafnium

(Metallurgical Society)

9:30 am — West Venetian Room

James R. Long *Chairman*, and Bruce S. Old, *Co-Chairman*

Hafnium—Its Metallurgy, Properties, and Application: *E. T. Hayes*, USBM
Zirconium: *Haruo Kato*, USBM
Porosity in Formed Titanium: *R. A. Wood, D. N. Williams, H. R. Ogden, and R. I. Jaffee*, Battelle Memorial Institute
Titanium Castings: *A. N. Roberson*, USBM
The 7 Aluminum-3 Molybdenum Titanium Alloy—A Review of Its Development and Properties: *F. A. Crossley*, Armour Research Foundation

Raw Materials, Exploration, and Reserves

(Society of Mining Engineers)

9:30 am — Colonial Room

Ian Campbell, *Chairman*, and Joseph H. Birman, *Co-Chairman*

World Potash Reserves: *R. W. Mumford*, American Potash & Chemical Corp.
USGS Investigations of Borates: *Ward C. Smith*, USGS
Effects of Clay upon Deposition of Uranium at Poison Canyon, N. M.: *H. C. Coleman*, Haystack Mountain Development Co.
Rare Earths: *Lloyd C. Pray*, Ohio Oil Co.

Luncheon Session

12:00 m — Cocoanut Grove

Speaker: *Harold M. Bannerman*, Assistant Director, USGS
Subject: *The Search for Mineral Raw Materials*

Fabrication

(Metallurgical Society)

2:00 pm — West Venetian Room

Benjamin S. Mesick, *Chairman*, and William V. Wright, Jr., *Co-Chairman*

Vacuum Melting of Reactive Metals in Arc Furnaces: *Stephen M. Shelton*, Oregon Metallurgical Corp.
Extrusion and Forging of Reactive Metals: *G. A. Moudry*, Harvey Machine Co.
Welding Reactive Metals: *Bruce Baird*, North American Aviation
Powder Metallurgy of Reactive Metals Used in Nuclear Engineering: *Henry H. Hausner*, Penn-Texas Corp.

Mining Operations

(Society of Mining Engineers)

2:00 pm — Colonial Room

F. J. Weishaupl, *Chairman*, and A. C. Dorenfeld, *Co-Chairman*

Mining Methods at Pine Creek Mine: *H. L. McKinley*, Union Carbide Nuclear Co.
Climax Operations: *John Goth*, Climax Molybdenum Co.
Haystack Uranium Mining Operations: *Clyde E. Stauder, Jr.*, Haystack Mountain Development Co.
Evaluation and Beneficiation of Reactive Metal Minerals: *W. Bilicke*, Engineers Syndicate Ltd.

Fellowship Hour

6:15 pm — West Venetian Room

Dinner Session

7:00 pm — West Venetian Room

Speaker: *James Boyd*, Vice President Exploration, Kennecott Copper Corp. (formerly Director, USBM)
Subject: *The Effect of the Location of Reactive Metal Resources on the Industrial Development of the United States*

WEDNESDAY, MAY 29

Beneficiation, Refining, and Future Trends

(Metallurgical Society, Society of Mining Engineers)

9:00 am — West Venetian Room

Dwight Sawyer, *Chairman*, and Morton Dorenfeld, *Co-Chairman*

The Alkali Metals—Present and Future: *Marshall Sittig*, The American Lithium Institute Inc.
The Role of Thorium in Atomic Energy: *C. C. Woolsey, Jr.*, Atomics International Div., North American Aviation
Titanium Metallurgy—Film with live commentary by *D. H. Baker, Jr.*, Electrometallurgical Experimental Station, USBM
Commercial Methods of Processing Lithium Ores: *S. L. Cohen and C. E. Berthold*, American Potash & Chemical Corp.

Luncheon Session

12:00 m — Embassy Room

Speaker: *Bruce S. Old*, President, Nuclear Metals Inc.
Subject: *Current Interests in Reactive Metals*

High-Melting Metals

(Metallurgical Society, Society of Mining Engineers)

2:00 pm — West Venetian Room

Leonard D. Jaffe, *Chairman*, and Pol Duwez, *Co-Chairman*

Mechanical Working of Arc-Cast Molybdenum Alloys: *George A. Timmons*, Climax Molybdenum Co.
Metallurgy of Vanadium: *William Rostoker*, Armour Research Foundation
Some Mechanical and Physical Properties of Niobium and Tantalum: *R. T. Begley and J. H. Beehtold*, Westinghouse Electric Corp.
Metallurgy of Beryllium and Its Alloys: *A. R. Kaufmann*, Nuclear Metals Inc.

Powder Metallurgy Group Visits New Jersey Plant

The Hob Nob Group visits U. S. Metals Refining Co.'s plant in Carteret, N. J. The trip on March 19, by the AIME New York Section Powder Metallurgy Group, included a tour of the experimental press research laboratory, shown above.

A plant visit was made to the Carteret, N. J., plant of U. S. Metals Refining Co., a subsidiary of American Metals Co. Ltd., on Wednesday, March 6. The plant trip was under the sponsorship of the AIME New York Section Powder Metallurgy Group.

After a luncheon provided by American Metals, guides took small groups through the plant, visiting the smelting and casting departments, the powder metallurgy department, and the tankhouse where copper is refined electrolytically.

U. S. Metals Refining Co. first made alloy powders in 1946, and in 1954 formally established a powder metallurgy department to conduct research in the field.

The group was welcomed to the plant by Freeman Dyke, vice president and general manager of U. S. Metals. Arrangements for the plant tour were made by Howard S. Cannon, supervisor of metal powder research for the company.

The next meeting of the New York Section Powder Metallurgy Group will be held on May 8, at the Brass Rail Restaurant, Fifth Ave. and 43rd St., New York. At that time, a talk will be given on the subject of *Sintering Mechanism* by A. J. Shaler of Pennsylvania State University. This will be a joint meeting with the New York Section Physical Metallurgy Group.

• The **Montana Section** met on February 14, at the Montana Power Auditorium in Butte, to hear an address by Richard R. Matthew. A member of the Montana Highway Department, Mr. Matthew spoke on *Soil Studies in the Treasure State*.

• At the dinner-meeting of the **Colorado Section** on February 21, at the University Club in Golden, the featured speaker was Fred Mace. In addition to his talk on *Operation Egypt*, Mr. Mace presented a film made by Kerr-McGee Oil Industries Inc., entitled *Through Suez For Oil*.

• The **Oregon Section** meeting on February 15, took place in the Burns Restaurant, with chairman Lloyd H. Banning presiding. Highlight of the program was a screening of the new Reynolds' color film, *Aluminum on the March*, introduced by Don Johnson. In the business meeting which preceded, the Section approved the annual donation to the Portland Library for the purchase of technical books, and Hollis Cole reported on student activities.

• The **Spokane Subsection** of the Columbia Section held a joint meeting with the ASME on Feb. 27, 1957, in the Gonzaga University Engineering Building. Highlight of the meeting was the talk by B. H. Jones who spoke on open pit copper mining in Utah. Mr. Jones who is an electrical engineer for Kaiser Aluminum Corp., illustrated his lecture with colored slides.

• The **Boston Section** was honored by the presence of Norbert Weiner as guest speaker at their dinner-meeting Feb. 4, in the MIT Faculty Club. Dr. Weiner, Professor of Mathematics at MIT, is internationally known for his contributions to mathematical theory and has written a book on cybernetics, the comparative study of the human brain and the electronic brain. His autobiography, published recently is entitled *Ex-Prodigy*. Dr. Weiner addressed the Section on the subject of *The Nervous System and the Control Machine*.

The Section met again on March 4, at the MIT Faculty Club in Cambridge, Mass. The dinner-meeting was a traditional honor to Professor Richards who contributed so much to the development of mineral engineering. Guest speaker for the occasion was A. M. Gaudin, who occupies the Richards Chair of Mineral Engineering at MIT. His topic was *Native Flotability and Crystal Structure*. The author of a book on flotation, which is now a standard text, Prof. Gaudin received the AIME Robert H. Richards Award this year.

• The **Yavapai Subsection** met at the Hassayampa Hotel in Prescott, Ariz., on January 31, to welcome five mining engineers from Spain who are visiting this country as guests of the U. S. State Dept. These visiting engineers were entertained by a cocktail party and a semiformal dinner. Other guests welcomed at the meeting were Thomas Bardon, president, Shattuck Denn Mining Corp.; Thomas Newell, of the same company; and William Zilbersher of Ventures Ltd. The meeting was presided over by the new chairman, David Lowell.

• Edward L. Pine, Associated General Contractors of America, addressed the engineers and guests at the regular meeting of the **Reno Subsection** on February 8, in the Nevada Room of the Hotel Mapes. He discussed the recent Reno blasts and fire, and the history of floods on the Truckee River, with special emphasis on the Reno floods of 1950 and 1955. In conclusion, Mr. Pine outlined the Washoe Project on the Truckee River Watershed and presented his recommendations for improvement of the Truckee River Channel and bridges in Reno.

Edmund F. Lawrence, mining geologist of the Nevada Bureau of Mines was selected as vice chairman of the Reno Subsection to succeed H. P. Ehrlinger, III, who resigned to accept a position with the American Smelting & Refining Co. at El Paso.

Milling and Smelting—**the Sudbury Nickel Ores, is a 16-mm sound color film produced by Inco, available free of charge. The 54-min movie combines animation and models with actual photography, presenting a complete picture of the operation. In addition, the history and formation of the Sudbury Basin deposit is described, the components of the material analyzed, and the combined efforts of research engineers, technicians and workers to solve the riddle of the rock is shown.**

Inco's earlier film, *Mining for Nickel*, **a 16-mm sound color film, of 45 min duration was reviewed in** MINING ENGINEERING, **October 1955. Both films are free and may be obtained from the distributor, Rothacker Inc., 729 Seventh Ave., New York, 19, N. Y. State first, second, and third choice of showing date.**

PERSONALS

S. STORCHEIM

Samuel Storcheim, former chief of nuclear manufacturing engineering and research, Glenn L. Martin Co., Baltimore, has become president and technical director, Metals Research and Development Corp., Exeter, Pa., a laboratory and consulting service for government agencies and private industry in the metal, cermet, and ceramic areas.

P. Coheur has become head of general metallurgy, the University of Liege, Belgium, succeeding H. Thyssen, who has retired.

R. W. Ruddle has resigned his position with the British Non-Ferrous Metals Research Assn. to become technical manager for Foundry Services Inc., Columbus, Ohio.

Donald N. Frey has been named director of engineering research, Ford Motor Co., Dearborn. Formerly associate director of the Scientific Laboratory, Mr. Frey recently served as

D. N. FREY

general chairman of the two-day AIME Regional Meeting on Deep Drawing Steels. He is a past chairman of the Detroit Section.

Donald L. Colwell, controller of laboratories at Apex Smelting Co., Chicago, was the speaker at the March 12 meeting of the Muncie, Ind., chapter of American Society for Metals. His topic was *Aluminum and Zinc Alloys in the Die Casting Process.*

R. W. Wilson has been named Chicago District Manager, Electro Metallurgical Co. He had been sales engineer for the company. At the same time, **F. W. Hanson** has been appointed Houston District Manager, after 18 years of service as sales and metallurgical engineer.

Howard N. Egan has been transferred from Gary, W. Va., to the Lynch, Ky., offices of U. S. Steel Corp. in the capacity of assistant chief engineer.

D. J. Penney is with U. S. Steel Export Co., New York.

W. E. KINGSTON

Walter E. Kingston, general manager of the Atomic Energy Div., Sylvania Electric Products Inc., has been named executive vice president of the newly-formed Sylvania-Corning Nuclear Corp., a joint venture of Sylvania and Corning Glass Works. His headquarters will remain in Bayside, N. Y. Mr. Kingston graduated from General Electric Co.'s Engineering School in 1927, and studied metallurgy at Massachusetts Institute of Technology.

Thomas M. Hogan has been named assistant district sales manager in the New Orleans office of Jones & Laughlin Steel Corp. Associated with the company for 20 years, Mr. Hogan had been senior salesman in the Detroit district sales office.

Carl M. Loeb, Jr. was one of three industrialists named division chairmen of the Petroleum and Metals Group in the New York City Cancer Committee's April Cancer Crusade. He is vice president and director of the nonferrous metals division, Climax Molybdenum Co.

V. W. JONES

The promotions of **Vernon W. Jones** and **John Poast** were recently announced by Armco Steel Corp., Middletown, Ohio. Mr. Jones, formerly superintendent of steel plant production, has been made assistant general superintendent, blast furnace and steel plant production. Prior to his employment at Armco on Jan. 1, 1928, he served as chemist, Charleston Alloy Steel Co., Bell, W. Va.; first helper, Hess Steel Corp., Baltimore; and was melter foreman, International Nickel Co., Huntington, W. Va. Mr. Poast, a graduate of Ohio State University had been a farmer prior to his employment at Armco in 1926. In 1934 he was promoted to analyst in the Metallurgical Dept., subsequently becoming quality checker, observer, and metallurgist. After appointments as assistant superintendent and superintendent in the Blast Furnace Dept., he was transferred to the Hamilton Plant, where he holds his present position of assistant general superintendent.

J. POAST

At the Bunker Hill Co., **A. Y. Bethune** has been promoted to manager of metallurgy, in charge of the company's extensive Kellogg, Idaho, operations. Succeeding Mr. Bethune as zinc plant superintendent is **Walter Schmittroth**, formerly number two man at the operation.

(Continued on page 722)

Personals

(Continued from page 721)

J. H. MOORE

James H. Moore, former general manager of Vacuum Metals Corp., has been made assistant to the president, Metal Hydrides Inc., Beverly, Mass. He will direct an intensive program of product development and marketing expansion for the company.

Frederick Forscher, Z. M. Shapiro and **L. P. Pepkowitz** are the founders of a new company, the Nuclear Materials & Equipment Corp., Apollo, Pa., which will supply products and services to the nuclear power industry. Dr. Forscher, formerly of Westinghouse Atomic Power Div., is vice president of the concern.

Charles E. Peterson has left Blaw-Knox Co., Rolls Div., Pittsburgh, to become chief metallurgist with the E. W. Buss Co., in the same city.

Col. William H. Bassett, Jr. has announced his retirement from the U. S. Army. He had been associated with the Ordnance School, Aberdeen Proving Ground, Md.

Robert J. Goode, formerly at Carnegie Institute of Technology, Pittsburgh, is working in the Naval Research Laboratory, Washington, D. C.

Joseph Kozol has accepted a position as metallurgist with Combustion Engineering Inc., Windsor, Conn.

Malcolm S. Grahm has completed his studies at the University of Wisconsin, Madison, and is stationed at Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, as a second lieutenant, USAF.

Gordon Crouch, formerly enrolled in Texas Western College, is in the U. S. Army, stationed at Fort Bliss, Texas.

Chih-Wen Chen formerly associated with the Columbia University School of Mines is now in the Magnetics Dept., Westinghouse Research Laboratories, Pittsburgh.

Two promotions at Bethlehem Steel Co. have recently been announced. **Joseph L. Walton,** formerly superintendent, Open Hearth Div. of the Lackawanna, N. Y. plant, has been appointed assistant general manager of Bethlehem's Johnstown, Pa. plant, while **Norman W. Fennie** has been promoted from assistant to superintendent of No. 3 Open Hearth.

James W. Kinnear, Jr. has been appointed executive vice president of U. S. Steel Corp.'s Tennessee Coal & Iron Div., Birmingham. Associated with U. S. Steel since 1923, Mr. Kinnear was vice president-operations of the division prior to his promotion. He is a graduate of Allegheny College and attended Massachusetts Institute of Technology, earning a B. S. degree in metallurgical engineering.

Wayne Myers has resigned as mining engineer for the Bunker Hill Mining and Concentrating Co., Kellogg, Idaho, to become associated with Union Carbide Nuclear Co., Bishop, Calif.

Donald C. Carmichael, a former student at Purdue University, W. Lafayette, Ind., has taken a job with Battelle Memorial Institute, Columbus, Ohio.

Zay Jeffries, retired vice president of General Electric Co., has been re-elected chairman of the board of trustees at Battelle Memorial Institute, Columbus, Ohio. Dr. Jeffries was recently appointed director general, of the Second World Metallurgical Congress to be held in Chicago, Nov. 2-8, 1957.

William T. McKeon and **John L. Peterson** have recently joined Electro Metallurgical Co., Pittsburgh.

Ernest A. Lado, formerly of Nichols Engineering & Research Corp., New York, has joined Metallurgical Resources Inc., Newburgh, N. Y.

Benny Kidd is now employed by Reynolds Metal Co., Little Rock, Ariz.

H. Rush Spedden, vice president, AIME Niagara Frontier Section, has been named Director of Research at Union Carbide Ore Co.'s research center, Sterling Forest, N. Y. His duties will include work in geophysics and geochemistry as well as geology, mineralogy, and mineral prospecting. Since 1952, Mr. Spedden has had charge of the Minerals Research Dept., Electro Metallurgical Co., Niagara Falls, N. Y.

P. J. Hughes has been appointed assistant to the works manager, Midvale-Heppenstall Co. He resumed his former association with the company in 1956, after resigning his position with Fairmount Steel Corp., Philadelphia.

OBITUARIES

Elmer A. Holbrook (Member 1908) died Feb. 20, 1957, in Pittsburgh. A former AIME director, the 76-year-old retired dean of the University Schools of Engineering and Mines had been suffering from a heart condition. He had served as Dean from 1927 until his retirement in 1950. Dr. Holbrook was the first recipient of AIME's MIED award last year. Born in Fitchburg, Mass., he received his degrees at Massachusetts Institute of Technology, and was presented with an honorary doctor's degree by the University of Illinois. He was the author of more than 100 technical articles on mining subjects and engineering education.

J. D. Sperr (Member 1915) died last November 21, in Oakland, Calif., at the age of 68. A native of Columbus, Ohio, he graduated from Michigan College of Mines in 1909. Mr. Sperr did exploration work in Canada and later worked for the U. S. General Land Office in Denver, Portland, Ore., and San Francisco.

Franz A. Vandestrick (Member 1952) died recently. Born in Charleroi, Belgium, on Nov. 25, 1894, he attended the School of Mines and Metallurgy at Mons, Belgium, receiving the degree of civil engineer in 1920. He joined the Societe Anonyme Metallurgique d'Esperance-Longdoz, Liege, Belgium, in that year as assistant to the blast furnace superintendent. In 1926, he became rolling mills superintendent, from which he advanced to chief superintendent of the steel works and rolling mills, finally becoming director of the organization.

Samuel J. Beckman (Member 1948) died in an automobile accident on Nov. 16, 1956, at the age of 33. A native of Buffalo, he was graduated in 1949 from Carnegie Institute of Technology and worked at Carnegie Illinois Steel Corp., Pittsburgh, before joining Jones & Laughlin Steel Corp. in 1950. A succession of positions, including strip mill tester, blooming mill inspector, and hot mill observer led to his appointment in 1951 as practice metallurgical investigator. Prior to entering Carnegie Institute, he had been employed by the Buffalo, Niagara, Electric Corp., Buffalo.

Robert C. Good (Member 1928) died Jan. 11, 1957. He was executive vice president, Union Electric Steel Corp., Pittsburgh. Born in Harrisburg, Pa., in 1895, Mr. Good attended Lehigh University, receiving his degree in metallurgical engineering in 1921. Before joining Union Electric, he was associated with Electro Metallurgical Co. in Pittsburgh for many years.

EJC Salary Survey

Just published, the EJC report on engineers salary structure for 1956, covers 107,000 engineering graduates —93,000 in industry; 10,000 in government; and 4,000 in education. Most complete to date, survey relates earnings to graduation year of B.S.'s with special tables for Ph.D.'s. Tables show earning scales in 13 major employment areas such as chemicals and allied products and public utilities. Government engineers divided into state and federal service and engineers in education, show teaching income and outside income. The report, entitled *Professional Income of Engineers*, is available at EJC, 29 W. 39th St., New York 18, N. Y. The 36-page printed booklet complete with tables and graphs costs $1.50 per copy.

Speakers Bureau

To meet demand by industry and lay groups for authorities in broad areas such as manpower, employment conditions, etc., EJC is informally expediting formation of panels and securing individual speakers for functions outside of EJC. Now extremely limited by own manpower shortage, EJC secretariat hopes to expand activity. Inquiries for speakers are welcomed.

Welcome, New Members

The Society of American Military Engineers and the American Institute of Consulting Engineers became, respectively, constituent and associate societies, as of Jan. 16, 1957.

General Assembly

Important ideas from 1957 EJC Assembly: Engineers' salaries have not kept pace with rising national economy, productivity and labor wages; merit rating and position evaluation advanced as means of salary administration; engineering manpower, a defense bottleneck; government taking new look at employed engineers salary-wise; overseas opportunities are vast. These and more in EJC Assembly proceedings available about March 15 at EJC, 29 W. 39th St., New York 18, N. Y. Report includes papers of national experts and floor discussions; price—$1.00 each copy.

ECPD-EJC

Joint meeting of executive committees of both organizations propose closer cooperation. EJC participates in ECPD's annual meeting in October 1957, and ECPD may participate in EJC's 1958 General Assembly.

Washington Eye

EJC staff assigned task of frequent check on developing trends in Executive and Legislative branches of Federal government, in which engineering profession may have interest. Purpose: to transmit information to you through EJC.

NECROLOGY

Date Elected	Name	Date of Death
1948	John C. Andersen	Dec. 12, 1956
1928	Harold B. Bernard	Unknown
1947	Charles W. Binckley	Dec. 12, 1956
1902	Russell T. Cornell	Feb. 16, 1957
1942	Daniel M. Coxe	Unknown
1944	Francis J. Dohrer	Mar. 30, 1956
1956	Tom Duckels	Unknown
1947	Wordsworth C. Elliott	Sept. 1956
1936	W. L. Goldston, Jr.	Jan. 22, 1957
1928	R. S. Good	Jan. 11, 1957
1950	Joseph Francis Joy	Feb. 19, 1957
1928	C. D. King	Mar. 24, 1957
1918	George D. Louderback	Jan. 27, 1957
1936	Ernest J. Maust	Unknown
1919	Donald Hugh McDougall	Dec. 4, 1956
1947	James W. Morgan	Feb. 1, 1957
1918	A. C. Munro	Nov. 15, 1956
1915	Harold M. Smyth	Dec. 19, 1956
1915	J. D. Sperr	Nov. 21, 1956
1913	Robert T. Walker	Jan. 24, 1957
1900	Haariem E. West	Jan. 9, 1957

Legion of Honor

MEMBERSHIP

Proposed for Membership

Metallurgical Society of AIME

Total AIME membership on Feb. 28, 1957, was 27,101; in addition 2,938 Student Associates were enrolled.

ADMISSIONS COMMITTEE

Harold K. Work, Chairman; Francis B. Foley; T. D. Jones; E. S. Machlin; J. H. Scaff; Paul Von Stein; T. B. Winkler.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

Members

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Kenneth Adams, Johannesburg, South Africa
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COMING EVENTS

May 6, AIME, NOHC Chicago Local Section, spring meeting, Phil Smidt's Restaurant, Chicago.

May 10, AIME, NOHC Eastern Section, plant trip, Colorado Fuel & Iron Corp., Claymont, Del.

May 10, AIME St. Louis Section, presidential visit and dinner-dance. Speaker: J. L. Gillson, AIME Vice President.

May 10-12, AIME, NOHC Western Section, field trip, U. S. Lime Products Corp., Las Vegas, Nev., area.

May 12-16, Electrochemical Soc., Statler Hotel, Washington, D. C.

May 17, 18, AIME New England Regional Conference, 11th annual meeting, Hotel Statler, Boston.

May 28-29, AIME, Reactive Metals Conference. Mining Branch sessions on May 28; Metals Branch sessions on May 28, 29. Ambassador Hotel, Los Angeles.

June 7, AIME, NOHC Southern Ohio Local Section, annual golf party, Middletown, Ohio.

Sept. 8-Oct. 9, Commonwealth Mining and Metallurgical Congress, British Columbia to Nova Scotia.

Oct. 9-11, Joint Solid Fuels Conference, ASME-AIME Coal Div., Chateau Frontenac, Quebec.

Oct. 18, AIME, NOHC Southern Ohio Local Section, annual meeting, Deshler-Hilton Hotel, Columbus, Ohio.

Oct. 30-Nov. 1, AIME Rocky Mountain Minerals Conference, Denver.

Nov. 1, AIME Pittsburgh Section and NOHC Pittsburgh Section, 12th annual Off-the-Record Meeting, Penn-Sheraton Hotel, Pittsburgh.

Nov. 4-6, AIME, IMD Fall Meeting, Morrison Hotel, Chicago.

Nov. 13, AIME, NOHC Buffalo Local Section, annual meeting, Hamilton, Ont., Canada.

Dec. 4-6, AIME, 15th Electric Furnace Steel Conference, Penn-Sheraton Hotel, Pittsburgh.

Feb. 16-20, 1958, AIME Annual Meeting, Hotel Statler, New York.

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